A

INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1882.

1809

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10 VICTORIA CHAMBERS, LONDON, S.W.

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1882.

ERRATA IN PROCEEDINGS 1882.

Page 124, line 13, *for* " counterweights B " *read* " counterweights E."

" 222 " 24, *for* " The brush now rises again " *read* " The brush B_1 now rises again."

" 421 " 11, *for* " main " *read* " mean."

" 454, to List of Works add " Leeds Industrial Co-operative Society's Flour Mills."

" 468, line 16, *for* " Thomson " *read* " Thompson."

Plate 64, Section of Erin Colliery, Westphalia, *for* " Scale 1 to 240 " *read* " Scale 1 to 4800," and correct the drawn scale accordingly.

OFFICERS.

1882.

PRESIDENT.

Percy G. B. Westmacott, ... Newcastle-on-Tyne.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne
Sir Frederick J. Bramwell, F.R.S., ... London.
Edward A. Cowper, ... London.
Thomas Hawksley, F.R.S., ... London.
James Kennedy, ... Liverpool.
John Ramsbottom, ... Alderley Edge.
John Robinson, ... Manchester.
C. William Siemens, D.C.L., LL.D., F.R.S., ... London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., .. Manchester.
Sir William Fairbairn, Bart., LL.D., F.R.S., (*deceased* 1874).
Robert Napier, ... (*deceased* 1876).
John Penn, F.R.S., ... (*deceased* 1878).
George Stephenson, ... (*deceased* 1848).
Robert Stephenson, F.R.S., ... (*deceased* 1859).

VICE-PRESIDENTS.

I. Lowthian Bell, F.R.S., ... Northallerton.
Charles Cochrane, ... Stourbridge.
Jeremiah Head, ... Middlesbrough.
George B. Rennie, ... London.
Charles P. Stewart, ... Sunninghill.
Francis W. Webb, ... Crewe.

MEMBERS OF COUNCIL.

Daniel Adamson, ... Manchester.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1882.

HONORARY LIFE MEMBERS.

1878. Crawford and Balcarres, Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; and Haigh Hall, Wigan.
1865. Downing, Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.
1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

MEMBERS.

1878. Abbott, Thomas, Northgate Iron Works, Newark.
1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, 60 Queen Victoria Street, London, E.C.
1875. Adams, Thomas, Ant and Bee Works, West Gorton, Manchester.
1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.
1848. Adams, William Alexander, Gaines, Worcester.
1881. Adams, William John, Messrs. Everitt Adams and Co., 35 Queen Victoria Street, London, E.C.

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester.

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.

1878. Adcock, Francis Louis, Post Office, Cape Town, Cape of Good Hope: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, 6 Delahay Street, Westminster, S.W.

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1870. Alexander, Alfred, King William's Town, Cape of Good Hope: (or care of William Alexander, East Cranhams, Cirencester.)

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, Savile Street Engineering Works, Sheffield.

1881. Allen, Percy Ruskin, Anglo-American Brush Electric Light Co., Victoria Works, Vine Street, York Road, Lambeth, London, S.E.; and Wood berrie Hill, Loughton, Essex.

1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1882. Allen, William Milward, Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of Richard Ruffell, Talanka, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, 2 Peel Street, London Road' Glasgow.

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1876. Allport, Charles James, 11 Queen Victoria Street, London, E.C.

1871. Allport, Howard Aston, Bestwood Coal and Iron Co., Nottingham; and The Park, Nottingham.

1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, 42 Queen Anne's Gate, Westminster, S.W.

1880. Anderson, James, Vyksounsky Iron Works, Mouram, Russia.

1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.

1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, 8 Buckingham Street, Adelphi, London, W.C.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.; and 3 Whitehall Place, London, S.W.

1878. Angas, William Moore, Messrs. Wilson Brothers and Co., Alliance Works, Darlington.

1858. Appleby, Charles Edward, Charing Cross Chambers, Duke Street, Adelphi, London, W.C.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Archer, David, Bond Court House, Walbrook, London, E.C.; and 5 Mount Pleasant Villas, Crouch Hill, London, N.

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford.

1859. Armitage, William James, Farnley Iron Works, Leeds.

1879. Armstrong, Alexander, Vulcan Foundry, Leet Street, Invercargill, Otago, New Zealand.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, Professor of Engineering, Yorkshire College of Science, Leeds.

1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham; and Bickenhill Hall, near Birmingham.

1879. Arrol, Thomas Arthur, Manager, Messrs. P. and W. MacLellan, Clutha Iron Works, Glasgow.

1857. Ashbury, James Lloyd, 6 Eastern Terrace, Brighton.

1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester; and 28A Market Street, Manchester. (*Life Member.*)

1881. Aspinall, John Audley Frederick, Locomotive Superintendent, Great Southern and Western Railway, Dublin.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.

1875. Atkinson, Edward, Messrs. Richards and Atkinson, Bank Street, Royal Exchange, Manchester; and 4 Richmond Hill, Bowdon, Cheshire. (*Life Member.*)

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester.

1879. Bagot, Alan Charles, Messrs. Apps and Bagot, 433 Strand, London, W.C.
1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley.
1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.
1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.
1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.
1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China: (or care of George Ogilvie, 110 George Street, Glasgow.)
1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.
1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.
1879. Baldwin, Thomas, 27 Brunswick Street, Cheetham, Manchester.
1877. Bale, Manfred Powis, 20 Budge Row, Cannon Street, London, E.C.
1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.
1882. Barber, John, 20 Park Row, Leeds.
1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.
1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.
1860. Barker, Paul, Church Road, Yardley, near Birmingham.
1882. Barlow, Henry Bernouilli, Cornbrook Heald Works, Chester Road, Manchester.
1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.
1866. Barnard, Clement, 4 Billiter Square, London, E.C.
1881. Barnett, John Davis, Assistant Mechanical Superintendent, Western Division, Grand Trunk Railway, Stratford, Ontario, Canada.
1878. Barr, James, Works Manager, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.
1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Gaythorn Station, Hulme, Manchester.
1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.
1862. Barrow, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.
1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.
1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 6 Stone Buildings, Lincoln's Inn, London, W.C.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1882. Beattie, Frank, Messrs. Morewood and Co., Soho, near Birmingham.

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward, Dallam Forge, Warrington; and 21 Bold Street, Warrington. (*Life Member.*)

1873. Beck, William Henry, 139 Cannon Street, London, E.C.

1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1858. Bell, Isaac Lowthian, F.R.S., Clarence Iron Works, Middlesbrough; and Rounton Grange, Northallerton; and 16 Eaton Place, London, S.W.

1880. Bell, William Henry, Bolivia: care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 38 Parliament Street, Westminster, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1878. Belsham, Maurice, Messrs. Frederick Hart and Co, 52 Queen Victoria Street, London, E.C.

1854. Bennett, Peter Duckworth, Horseley Iron Works, Tipton.

1877. Bennett, Thomas Oldham, Post Office, Melbourne, Victoria.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1879. Bergeron, Charles, 2 Edinburgh Mansions, Victoria Street, Westminster, S.W.

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, Haydon Bridge, Northumberland.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Surveyor, St. Katharine Dock House, London, E.; and 45 Highbury Quadrant, London, N.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1881. Blechynden, Alfred, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1881. Bocquet, William, Locomotive Engineer, Scinde Punjaub and Delhi Railway, Lahore, India.

1863. Boeddinghaus, Julius, Machine Works and Iron Foundry, Düsseldorf, Germany.

1880. Borodine, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1869. Borrie, John, Cranbourne Terrace, Yarm Lane, Stockton-on-Tees.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P. O. Box 2220, San Francisco, California, United States.

1869. Boyd, William, Wallsend Slipway and Engineering Co., Wallsend, near Newcastle-on-Tyne.

1875. Braconnot, Capt. Carlos, Chief Director and Engineer of the Marine Arsenal, Correio Geral, Caixa 232, Rio de Janeiro, Brazil; and 17 bis, Boulevard Eugène, Neuilly, Seine, France.

1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.

1878. Bradley, Frederick Augustus, 39 Queen Victoria Street, London, E.C.

1881. Bradley, Thomas, Wellington Foundry, Newark.

1854. Bragge, William, Clarendon House, 59 Hall Road, Handsworth, Birmingham.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Works, Wednesbury.

1854. Bramwell, Sir Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, Messrs. Breeden and Booth, Cheapside Works, 157 Cheapside, Birmingham.

1881. Briggs, John Henry, Engineer, Kimberley Water Works, Kimberley, South Africa: (or care of Charles Briggs, Howden.)

1881. Briggs, Robert, United States Engineer Office, 1125 Girard Street, Philadelphia, U.S.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1879. Brodie, John Shanks, Assistant to Borough and Water Engineer, Municipal Offices, Liverpool.

1852. Brogden, Henry, Hale Lodge, Altrincham, near Manchester. (*Life Member.*)

1877. Bromley, Massey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, Belvedere Road, Lambeth, London, S.E.; and 25 Ladbroke Gardens, Notting Hill, London, W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1879. Brown, Charles, Manager, Swiss Locomotive and Machine Works, Winterthur, Switzerland: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Manager, Grand Trunk Railway Locomotive Works, Montreal, Canada.

1881. Brown, George William, Reading Iron Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1869. Browne, Benjamin Chapman, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1874. Browne, Tomyns Reginald, Assistant District Locomotive Superintendent, East Indian Railway, Allahabad, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1869. Browne, Walter Raleigh, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta; and 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, F.R.S.E., 5 Victoria Street, Westminster, S.W.
1872. Brunner, Henry, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Cliff House, Appleton, Widnes.
1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.
1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, 52 Park Street, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)
1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.
1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.
1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester.
1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile.
1881. Bulkley, Henry Wheeler, 149 Broadway, New York.
1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.
1877. Burgess, James Fletcher, Messrs. Ormerod Grierson and Co., 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.
1874. Burn, William Edward, 173 Portland Road, Newcastle-on-Tyne.
1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford.
1877. Burton, Clerke, Post Office Chambers, Bute Docks, Cardiff.
1870. Bury, William, 5 New London Street, London, E.C.
1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1882. Butler, Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.
1880. Campbell, Daniel, 3 Westminster Chambers, Victoria Street, Westminster, S.W.
1864. Campbell, David, 151 Eglinton Street, Glasgow.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.
1882. Campos, Raphael Martinez, 598 General Lavalle, Buenos Aires.
1860. Carbutt, Edward Hamer, M.P., 19 Hyde Park Gardens, London, W.; and Llanwern House, Monmouthshire.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Nagpur and Chattisgarh State Railway, Nagpur, Central Provinces, India: (or care of Messrs. King, King and Co., Bombay.)

1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.) (*Life Member.*)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1869. Carpmael, Frederick, 57 Arlingford Road, Tulse Hill Gardens, Brixton, London, S.W.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C.

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1874. Carrington, William T. H., 9 and 11 Fenchurch Avenue, London, E.C.

1876. Carson, William, Egremont, Birkenhead.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1877. Carter, William, Managing Engineer, Birmingham Patent Tube Works, Smethwick, near Birmingham; and Imperial Tube Works, Birmingham.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton; and Irwell House, Drinkwater Park, Prestwich, near Manchester.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1882. Church, Charles Simmons, Resident Engineer, Water Works, Barranquilla, United States of Colombia; and Chacewater Vicarage, Scorrier, Cornwall.

1880. Churchward, George Dundas, Post Office, Launceston, Tasmania; and Kersney Manor, Dover.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1859. Clark, George, Southwick Engine Works, near Sunderland.

1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds.

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1878. Closson, Prosper, 48 Rue Laffitte, Paris.

1882. Coates, Joseph, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1859. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, Ordnance Cotton Mill, Blackburn.

1876. Coe, William John, 1 Rumford Place, Liverpool.

1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.

1878. Cole, John William, care of Messrs. J. Stilling and Co., Adelaide, South Australia.

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1877. Coley, Henry, 10 Hopton Road, Coventry Park, Streatham, London, S.W.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1874. Conyers, William, Dunedin, Otago, New Zealand.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1875. Cooper, Frederick, Chief Engineer, H. M. Gun Carriage Department, Bombay.

1877. Cooper, George, Engineer and General Manager, Buenos Ayres Great Southern Railway, Buenos Ayres: (or care of Secretary, Buenos Ayres Great Southern Railway, 4 Great Winchester Street, London, E.C.)

1874. Cooper, William, Neptune Foundry, Hull.

1881. Coote, Arthur, Messrs. Andrew Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness.

1878. Cornes, Cornelius, 30 Walbrook, London, E.C.

1848. Corry, Edward, 8 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India.

1875. Cotton, Francis Michael, Messrs. Field Field and Cotton, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.; and 2 Courthope Villas, Wimbledon, Surrey.

1875. Cottrill, Robert Nivin, Beehive Works, Bolton.

1868. Coulson, William, Mining Engineer, 32 Crossgate, Durham; and Shamrock House, Durham.

1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.

1882. Courtney, William McDougall, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.

1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1870. Cowen, George Roberts, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham; and 9 Rope Walk Street, Nottingham.

1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.

1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.

1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.

1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.

1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.

1877. Crompton, Rookes Evelyn Bell, Messrs. T. H. P. Dennis and Co., Anchor Iron Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1881. Crosland, James Foyell Lovelock, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1882. Cross, William, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1871. Crossley, William, 153 Queen Street, Glasgow.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1882. Cruickshank, William Douglas, Chief Engineer Surveyor, Marine Board, Sydney.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's, Lancashire.

1881. D'Alton, Patrick Walter, Crohill, Angles Road, Streatham, London, S.W.

1866. Daniel, Edward Freer, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent; and 11 Needwood Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.

1879. Darling, William Littell, Manager of Steel Works, Dowlais Iron Works, Dowlais.

1878. Darwin, Horace, 66 Hills Road, Cambridge. (*Life Member.*)

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.

1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Davidson and Lees, 24 Basinghall Street, London, E.C.)

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Superintendent, Holkar and Sindia-Neemuch State Railway, Khandwa, India.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 64 Cannon Street, London, E.C.

1877. Davison, John Walter, Messrs. William and John Davison, Engineers and Ironfounders, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1874. Daw, Samuel, Pearston House, 23 The Walk, Tredegarville, Cardiff.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.

1879. Dawson, Bernard, The Laurels, Malvern Link, Malvern.

1876. Dawson, Thomas Joseph, Mining Engineer, Cocken, near Fence Houses.

1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool; and Dacre Hill, Birkenhead.

1880. Deacon, Richard William, Kalimaas Works, Soerabaya, Java.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, North Street, Leeds.

1882. Denny, William, F.R.S.E., Messrs. William Denny and Sons, Leven Ship Yard, Dumbarton.

1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1868. Derham, John J., Brookside, near Blackburn.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland.

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Railway Wheel and Axle Works, Stourbridge.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.

1873. Dobson, Richard Joseph Caistor, Volharding Iron Works, Soerabaya, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn.

1880. Donald, James, Messrs. Fraser and Miller, Carnac Iron Works, Bombay.

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, Engineer to the Trinity Board, Trinity House, London, E.C.

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Lambeth Pottery, Lambeth, London, S.E.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 35 Queen Victoria Street, London, E.C.

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C.

1870. Dunlop, James Wilkie, 49 Albert Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1587, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1877. Edwards, Frederick, Superintending Engineer, Weymouth and Channel Islands Steam Packet Co., &c., 127 Leadenhall Street, London, E.C.

1880. Edwards, Robert, 9 Launder Terrace, Grantham.

1866. Elce, John, 25 Cathedral Yard, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Sons, Plymouth Foundry, Plymouth.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1882. Elliott, Thomas Graham, Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1870. Elsdon, Robert, 3 Poet's Corner, Westminster, S.W.; and 76 Manor Road, Upper New Cross, London, S.E.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Eyth, Max, 4 Münsterstrasse, Bonn, Germany.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, M.P., Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas C., Burmantofts Foundry, Leeds.

1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.

1876. Fell, John Corry, 23 Rood Lane, Fenchurch Street, London, E.C.

1877. Fenton, James, Manager, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.

1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India.

1881. Ferguson, William, 28 Lansdowne Road, Dublin.

1854. Fernie, John, P.O. Box 57, Philadelphia, Pennsylvania, United States.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Messrs. Field Field and Cotton, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1865. Filliter, Edward, 16 East Parade, Leeds.

1874. Firth, William, Burley Wood, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C.

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Westbromwich.

1882. Fletcher, David Hardman, Messrs. W. Collier and Co., Worsley Street' New Bailey Street, Salford.

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, Old Trinity House, 5 Water Lane, Great Tower Street, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1878. Fontaine, Marc Berrier-, Ingénieur de la Marine, Toulon Dockyard, Toulon, France.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta: or care of John Addison, Hawbush, Brettell Lane, Stourbridge.

1882. Forbes, William George London Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.
1882. Forsyth, Robert Alexander, 28 Tunnel Terrace, Newport, Monmouthshire.
1882. Fothergill, John Reed, Superintendent Marine Engineer, 70 Whitby Street, West Hartlepool.
1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.
1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.
1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.
1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.
1875. Fox, Samson, Leeds Forge, Leeds.
1882. Fox, William, Leeds Forge, Leeds.
1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E.
1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.
1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.
1882. Furrell, Edward Wyburd, 11 Southampton Buildings, Chancery Lane, London, W.C.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.
1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.
1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co. Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.
1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, near Saxmundham.
1882. Garrett, Richard, Messrs. Richard Garrett and Sons, Leiston Works, near Saxmundham.
1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough.
1878. Geach, John Jabez, New Passage, near Bristol.
1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.
1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.
1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.
1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Broad Green House, Norton, Stockton-on-Tees.
1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.
1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.
1878. Gimson, Josiah, Welford Road Engine Works, Leicester.

1881. Girdwood, William Wallace, Indestructible Packing Works, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.

1880. Godfrey, William Bernard, 54 Regent's Park Road, Regent's Park, London, N.W.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland.

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester.

1867. Gooch, William Frederick, Vulcan Foundry, Warrington.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)

1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E.

1880. Gottschalk, Alexandre, 17 Rue Laffitte, Paris.

1877. Goulty, Wallis Rivers, Albert Chambers, Albert Square, Manchester.

1871. Gowenlock, Alfred Hargreaves, Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta; and Phœnix House, Alleyne Park, West Dulwich, London, S.E.

1878. Grafton, Alexander, 113 Cannon Street, London, E.C.

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 35 Beresford Road, Highbury New Park, London, N.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Edward, Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Landore Siemens-Steel Works, Landore R.S.O., South Wales.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. Griffiths, John Alfred, Engineer, Waste Water Meter Co., 32 Park Lane, Liverpool; and 93 Wordsworth Street, Liverpool.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Cardiff Foundry, East Moors, Cardiff.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Sunnyside, Sandon Road, Edgbaston, Birmingham.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby; and 39 Hartington Street, Derby.

1880. Hallett, John Harry, 120 Powell's Place, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1870. Hamand, Arthur Samuel, 9 Bridge Street, Westminster, S.W.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, São Paulo, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1879. Handyside, James Baird, Messrs. Thomson Sterne and Co., Crown Iron Works, Glasgow.

1870. Hannah, Joseph Edward, Liverpool Corporation Water Works, Llansilin, near Oswestry.

1874. Harding, William Bishop, IX. Bez., Uellöerstrasse Nr. 35, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1873. Harman, Harry Jones, Chief Engineer, English and Scottish Boiler Insurance Company, 100 King Street, Manchester.

1879. Harris, Henry Graham, 37 Great George Street, Westminster, S.W.

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1879. Harrison, George, 1 Arthur's Grove, Leicester Street, Hull.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1865. Harrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.

1874. Hart, James, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1877. Hart, James, Borough Engineer and Surveyor, Town Hall, St. Helen's, Lancashire.

1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.

1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Govan, near Glasgow.

1878. Harwood, Robert, Soho Iron Works, Bolton.

1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C.

1881. Haslam, Alfred Seale, Union Foundry, Derby.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. *(Life Member.)*

1878. Haughton, Thomas, 122 Cannon Street, London, E.C.

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.

1882. Hayes, Edward, Watling Works, Stony Stratford.

1879. Hayes, John, 27 Leadenhall Street, London, E.C.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.
1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1873. Headly, Lawrance, 1 Camden Place, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, 9 Rumford Place, Liverpool.
1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.
1878. Hedges, Killingworth William, 25 Queen Anne's Gate, Westminster, S.W.
1875. Heenan, Richard Hammersley, Messrs. Heenan and Woodhouse, Newton Heath Iron Works, near Manchester.
1879. Henchman, Humphrey, Cape Government Railways, Uitenhage, Cape of Good Hope: (or care of John Henchman, Uplands, Wallington, Surrey).
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China; and Gattaway, Abernethy, Newburgh, Fife.
1878. Henesey, Richard, Messrs. Richardson and Cruddas, Bombay.
1879. Henriques, Cecil Quixam, 3 Poet's Corner, Westminster, S.W.
1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.
1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.
1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.
1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.
1872. Hewlett, Alfred, Haseley Manor, Warwick.
1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.
1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.
1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.
1870. Higson, John, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.
1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, Yorkshire.
1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.
1873. Hilton, Franklin, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham; and 62 Blackfriars Road, London, S.E.

1870. Hodges, Petronius, 171 Burngreave Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.

1852. Holcroft, James, Norton, near Stourbridge.

1866. Holcroft, Thomas, Bilston Foundry, Bilston.

1865. Holliday, John, Messrs. John Bethell and Co., Creosote Works, Westbromwich; and Oakfield Lodge, Booth Street, Handsworth, Birmingham.

1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.

1873. Holt, Henry Percy, Fairlea, Palatine Road, Didsbury, Manchester.

1867. Holt, William Lyster, 1 Pelham Place, South Kensington, London, S.W.

1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.

1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.

1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.

1856. Hopkinson, John, Grove House, Oxford Road, Manchester.

1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.

1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 46 Queen Street, Edinburgh.)

1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1880. Hornsby, William, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.

1868. Horsley, Thomas, King's Newton, near Derby.

1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.

1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.

1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.

1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.

1873. Hoskin, Richard, 1 East Parade, Sheffield.

1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, M.P., Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire.

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1861. Howell, Joseph Bennett, Messrs. Howell and Co, Brook Steel Works, Brookhill, Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1882. Howl, Edmund, Messrs. Lee Howl Ward and Howl, Tipton.

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W.

1882. Hudson, John George, Messrs. Mirrlees Watson and Co., 45 Scotland Street, Glasgow.

1881. Hughes, Edward William Mackenzie, Locomotive Superintendent, Indus Valley State Railway, Adamwahan, Punjaub, India.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1873. Hughes, Henry, Falcon Iron Works, Loughborough.

1871. Hughes, Joseph, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven; and Moresby, near Whitehaven.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Humphrys, James, Anglo-American Brush Electric Light Co., 108 Belvedere Road, Lambeth, London, S.E.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1865. Hyde, Major-General Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 11 Queen Street, Oldham.

1882. Inglis, John, 14 Praya Central, Hong Kong, China.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Budapest, Hungary.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Grosmont, near Hereford.

1873. Jackson, Samuel, Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Horseley Iron Works, Tipton.

1876. Jacobs, Charles Mattathias, 126 Bute Docks, Cardiff.

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne.

1870. Jamieson, John Lennox Kincaid, 9 Crown Terrace, Dowanhill, Glasgow.

1882. Jardine, John, Lace Machine Works, Raleigh Street, Nottingham.

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Jemson, James, 7 Ashton Terrace, Preston.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1878. Jensen, Peter, Messrs. Brewer and Jensen, 33 Chancery Lane, London, W.C.

1878. Jessop, Joseph, London Steam Crane and Engine Works, Leicester.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1882. Johnson, Charles Malcolm, Chief Engineer, H. M. Ironclad "Swiftsure," 11 Napier Street, Stoke, Devonport.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

1882. Jolin, Philip, Great Western Electric Light and Power Co., 16 High Street, Bristol; and Paulatim Club, 10 Adelphi Terrace, London, W.C.

1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, 5 Church Terrace, Queen's Road, Battersea, London, S.W.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1878. Jones, Frederick Robert, Whitehead Torpedo Works, Fiume, Austria: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Sakkur, near Karachi, Punjaub, India: (or care of Mrs. Edward Jones, Woodville, Wylde Green, near Birmingham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1880. Joy, David, 32 Anerley Park, Anerley, London, S.E.
1878. Jüngermann, Carl, Märkisch Schlesische Maschinenbau und Hütten Actien Gesellschaft, 3 Chaussée Strasse, Berlin.

1882. Keeling, Herbert Howard, Merleswood, Eltham.
1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.
1867. Kellett, John, Clayton Street, Wigan.
1873. Kelson, Frederick Colthurst, Greenbank, Waterloo, near Liverpool.
1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.
1863. Kennan, James, Messrs. Kennan and Sons, Engineering Works, Fishamble Street, Dublin.
1879. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.
1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.
1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.
1868. Kennedy, Thomas Stuart, Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds.
1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Maple Bank, Church Road, Edgbaston, Birmingham.
1866. Kershaw, John, 1 Arlington Street, Piccadilly, London, S.W.
1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemberg, Germany.
1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.
1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lancefield House, Glasgow; and Govan Park, Govan, Glasgow.
1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington.
1875. Kirkwood, James, Inspector of Machinery for Pei Yang Squadron; care of Commissioner of Customs, Tientsin, China.
1882. Kirkwood, Thomas, Harbour Engineer, Hong Kong and Whampoa Dock Co., Hong Kong, China.
1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.
1859. Kitson, James, Jun., Monk Bridge Iron Works, Leeds.
1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.
1874. Klein, Thorvald, Staffordshire Rolling Stock Co., Cliff Vale Wagon Works, Stoke-upon-Trent.
1875. Knight, John Henry, Weybourne House, Farnham.

1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts, West Indies: (or care of G. D. Kortright, Plas Teg, near Mold, Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.

1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1863. Lancaster, John, Bilton Grange, Rugby.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of William G. Parsons, 11 Queen Victoria Street, London, E.C.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer in Chief, Great Eastern Railway, Liverpool Street, London, E.C.

1879. Lapage, Richard Herbert, 13A Great George Street, Westminster, S.W.; and Craigleith, Paragon Road, Surbiton, Kingston-on-Thames.

1879. Larsen, Jorgen Daniel, 7 Poultry, London, E.C.; and 27 Dalhousie Square, Calcutta.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne.

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1856. Laybourne, Richard, Isca Foundry, Newport, Monmouthshire.

1860. Lea, Henry, 38 Bennett's Hill, Birmingham.

1865. Ledger, Joseph, Keswick.

1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 1 Rue du Charolais, Paris: (or care of Messrs. Sharp Stewart and Co., Atlas Works, Manchester.)

1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn, Newcastle-on-Tyne.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, 116 Fenchurch Street, London, E.C.; and 2 Granville Park, Blackheath, London, S.E.

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1867. Lloyd, Charles, 167 Howard Place, Shelton, Stoke-upon-Trent.

1871. Lloyd, Francis Henry, Darlaston Steel and Iron Works, near Wednesbury; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire; and Priors Lee Hall, near Shifnal.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1864. Lloyd, Sampson Zachary, Areley Hall, Stourport.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Company, 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, Messrs. Shand Mason and Co., Upper Ground Street, Blackfriars, London, S.E.

1882. Lord, Walter, Messrs. Lord Brothers, Canal Street Works, Todmorden.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C.

1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.

1877. Lupton, Arnold, Crossgates, near Leeds.

1878. Lüthy, Robert, Manager, Soho Iron Works, Bolton.

1854. Lynde, James Gascoigne, 32 St. Ann's Street, Manchester.

1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1879. Macdonald, Augustus VanZundt, Manager, Auckland Section, New Zealand Railways, Auckland, New Zealand.

1864. Macfarlane, Walter, Saracen Foundry, Possilpark, Glasgow.

1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)

1877. MacLellan, John A., Messrs. Alley and MacLellan, 2 Peel Street, London Road, Glasgow.

1864. Macnab, Archibald Francis, Yokohama United Club, Yokohama, Japan.

1865. MacNay, William, Shildon Engine Works, Darlington.

1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.; and Rotherham.

1878. Madge, Henry James, Engineer Inspector of Steam Boilers, 19 Lall-Bazar Street, Calcutta.

1879. Maginnis, James Porter, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1881. Mallory, George Benjamin, 55 Broadway, New York.

1882. Mañé, Marcos, Talleres, Ferro Carril Oeste, Buenos Aires.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway; The Hawthorns, 2 Highgate Rise, London, N.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Frederick Thorpe, M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1882. Mappin, Walter Sandell, 15 Holborn Viaduct, London, E.C.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.

1878. Marié, George, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1877. Marshall, William Bayley, 15 Augustus Road, Birmingham.

1847. Marshall, William Prime, 15 Augustus Road, Birmingham.

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Hanwell, Middlesex, W.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1854. Martineau, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.

1880. Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1882. Matheson, Henry Cripps, care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.

1875. Matthews, James, 46 Victoria Street, Bristol.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Saude, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1853. Maudslay, Henry, Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.) (*Life Member.*)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, care of Messrs. Peirce Leslie and Co., 2 Lime Street Square, London, E.C.
1874. McClean, Frank, 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1878. McDonald, John Alexander, 4 Chapel Street, Cripplegate, London, E.C.
1865. McDonnell, Alexander, Locomotive Superintendent, North Eastern Railway, Gateshead.
1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C.
1868. McKay, Benjamin, Ice Works, Rockhampton, Queensland: (or care of Messrs. Lear Phillips and Co., 38 Dean Street, Birmingham).
1881. McKay, John, Messrs. R. and W. Hawthorn, St. Peter's Works, Newcastle-on-Tyne.
1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley.
1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.
1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1881. Meik, Charles Scott, 6 York Place, Edinburgh.
1858. Meik, Thomas, 6 York Place, Edinburgh.
1857. Menelaus, William, Dowlais Iron Works, Dowlais.
1878. Menier, Henri, 37 Rue Ste. Croix de la Bretonnerie, Paris.
1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.
1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C.
1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.
1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.
1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitehaven.

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1882. Molesworth, James Murray, Chinese Engineering and Mining Co., care of H. B. M. Consulate, Tientsin, China.

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1882. Moore, Richard St. George, Messrs. Clarke and Moore, Exchange Buildings, Hull.

1872. Moorsom, Warren Maude, Linden Lodge, Clevedon.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1880. Morris, Edward Russell, Messrs. Charles Powis, Carter, and Morris, Cyclops Works, Millwall Pier, London, E.; and 1 Heath Mount, Hampstead, London, N.W.

1868. Morris, William, Waldridge Colliery, Chester-le-Street.

1865. Mosse, James Robert, General Director of Ceylon Railways; Conservative Club, 74 St. James' Street, London, S.W.

1858. Mountain, Charles George, Eagle Foundry, Broad Street, Birmingham.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 26 King Street, Manchester.

1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. Murdock, William Mallabey, Sun Foundry, Dewsbury Road, Leeds.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1848. Napier, John, 23 Portman Square, London, W.

1861. Naylor, John William, Messrs. Fairbairn Kennedy and Naylor, Wellington Foundry, Leeds.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1879. Neville, Robert, Butleigh Court, Glastonbury.

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. Newdigate, Albert Lewis, 25 Craven Street, Charing Cross, London, W.C. (*Life Member.*)

1881. Newman, Frederick, 5 Copthall Buildings, London, E.C.

1881. Nichol, Bryce Gray, Messrs. Donkin and Nichol, St. Andrew's Iron Works, Newcastle-on-Tyne.

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India.

1877. Nicolson, Donald, New Zealand Chambers, 34 Leadenhall Street, London, E.C.

1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.

1866. Norfolk, Richard, Beverley.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 125 Queen's Road, Peckham, London, S.E.

1882. Nunneley, Thomas, Messrs. Dawson and Nunneley, Black Bull Street, Hunslet, Leeds.

1868. O'Connor, Charles, Mersey Steel and Iron Works, Caryl Street, Liverpool.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C.

1880. Oldham, Robert Augustus, care of Messrs. Oldham Brothers, 110 Cannon Street, London, E.C.

1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.

1882. Olrick, Harry, 27 Leadenhall Street, London, E.C.

1882. Orange, James, Surveyor General's Department, Hong Kong, China.

1880. Ormiston, Thomas, C.I.E., Consulting Engineer to the Bombay Port Trust, Ormidale, Thurlow Park Road, West Dulwich, London, S.E.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1868. Paget, Arthur, Machine Works, Loughborough.

1881. Palmer, Cecil Brooke, Stanton Iron Works, Nottingham.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees.

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Pershouse, 25 Exchange Buildings, Birmingham.

1881. Parry, Henry, 2 Side, Newcastle-on-Tyne.

1880. Parsons, The Hon. Charles Algernon, 7 Ashwood Terrace, Headingley, Leeds.

1878. Parsons, The Hon. Richard Clere, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1877. Paton, John McClure Caldwell, care of Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1881. Pattinson, John, Locomotive Superintendent, Riazan and Kosloff Railway, Kosloff, Russia: (or care of Nathaniel Grew, Dashwood House, 9 New Broad Street, London, E.C.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1880. Peache, James Courthope, London and North Western Railway, Locomotive Department, Crewe.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1879. Pearce, George Cope, 2 St. Helen's Crescent, Swansea.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 46 Sinclair Road, Kensington, London, W.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1882. Perry, Alfred, Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, Post Office, Brisbane, Queensland: (or care of Messrs. Manlove Alliott Fryer and Co., Ilkeston Road, Nottingham.)

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore, Madras: (or 7 Teneriffe Street, Broughton, Manchester.)

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne Rouen, France.

1882. Pirrie, John Sinclair, Messrs. Fraser and Miller, Carnac Iron Works, Bombay: (or care of Messrs. Ironside Gyles and Co., 5 Barge Yard, Bucklersbury, London, E.C.)

1879. Pitt, Robert, Messrs. Stothert and Pitt, Newark Foundry, Bath.

1878. Pitts, George Albert, care of Messrs. J. and W. Pitts, St. John's, Newfoundland; and care of T. A. Readwin, 8 Bloomsbury Square, London, W.C.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Avonside Engine Works, Bristol; and 8 Albion Villas, Sydenham Park, London, S.E.

1869. Player, John, Clydach Foundry, near Swansea.

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Powell, William, Carleton, Pontefract.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.

1856. Preston, Francis, Turnbridge Iron Works and Forge, Huddersfield; and Netherfield House, Kirkburton, near Huddersfield.

1877. Price, Henry Sherley, Albert Chambers, Albert Square, Manchester.

1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.

1875. Prior, Johannes Andreas, 33 Bredgade, Copenhagen.

1874. Prosser, William Henry, Messrs. Harfield and Co., Mansion House Buildings, Queen Victoria Street, London, E.C.

1875. Provis, George Stanton, Whitehall Club, Parliament Street, Westminster, S.W.

1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.

1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.

1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.

1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1878. Rait, Henry Milnes, Messrs. Rait and Lindsay, Cranstonhill Foundry, Glasgow; and 155 Fenchurch Street, London, E.C.

1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1878. Ramsden, Robert, 177 Kingsland Road, London, E.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Head and Jefferies, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ratliffe, George, 3 South Hill Road, Liverpool.
1862. Ravenhill, John R., 27 Courtfield Gardens, South Kensington, London, S.W
1872. Rawlins, John, Manager, Metropolitan Railway Carriage and Wagon Works, Saltley, Birmingham.
1878. Rawlinson, Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.
1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.
1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada.
1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland.
1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W.
1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.
1878. Rennie, John, care of H. T. Lannigan, 39 Upper Thames Street, London, E.C.
1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.
1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields.
1876. Restler, James William, Assistant Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.
1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.
1879. Reynolds, George Bernard, Assistant Manager, Warda Coal State Railway, Warora, Central Provinces, India: (or care of Messrs. Stilwell, 22 Arundel Street, Strand, London, W.C.)
1882. Rhodes, Vincent, Messrs. Richard Hornsby and Sons, Grantham.
1875. Rich, William Edmund, Engineer, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.
1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1882. Richards, George, Messrs. George Richards and Co., 12 City Road, Manchester.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1881. Richardson, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1863. Rigby, Samuel, Fern Bank, Liverpool Road, Chester.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1879. Rixom, Alfred John, Woodstone Steam Brick and Tile Works, Peterborough; and 38 The Grove, Hammersmith, London, W.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Port Huron, Michigan, United States.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Andrew Bruce, 46 Queen Victoria Street, London, E.C.)

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Rochdale.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, care of Messrs. C. H. B. Forbes and Co., Bombay.

1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.

1868. Rogers, William, Estrada de Ferro das Alagoas (Central), Maceio, Brazil: (or care of J. Kenyon Rogers, 25 Water Street, Liverpool.)

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.

1874. Ross, John Alexander George, 46 Grainger Street West, Newcastle-on-Tyne.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1860. Rumble, Thomas William, F.R.S.E., Chief Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E. (*Life Member.*)

1878. Russell, The Hon. William, George Town, Demerara; and 65 Holland Park, London, W.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.

1877. Rutter, Edward, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C.

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and 33 St. James' Square, London, S.W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1864. Samuda, Joseph D'Aguilar, Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.

1865. Samuelson, Bernhard, M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Norland Works, Wharf Road, Latimer Road, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, Dutchlands, Springfield Park, Acton, London, W.

1881. Sandiford, Charles, Locomotive Superintendent, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.

1882. Sawyer, Frederic Henry Read, 18 Calle Real de San Miguel, Manila, Philippine Islands; and 4 Cullum Street, London, E.C.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1880. Schram, Richard, 9 Northumberland Street, Strand, London, W.C.

1876. Scott, David, Bengal Club, Calcutta.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport.

1881. Scott, George Innes, 4 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1881. Scott, James, Despatch Wool-Washing Co., Port Elizabeth, Algoa Bay, Cape Colony: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1861. Scott, Walter Henry, Park Road, East Molesey, Kingston-on-Thames.

1868. Scriven, Charles, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1882. Seabrooke, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham; and Oak Cottage, Windsor.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania United States.

1881. Sennett, Richard, Devonport Dockyard, Devonport.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta.

1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.

1867. Sharpe, Charles James, 27 Great George Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.

1882. Sharrock, Samuel Lord, Hydraulic Engineering Co., Chester.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Bristol.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Jun., Stanners Closes Steel Works, Wolsingham, near Darlington.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, D.C.L., LL.D., F.R.S., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Bayswater Road, London, W.

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1877. Simonds, William Turner, Messrs. J. C. Simonds and Son, Oil Mills, Boston. (*Life Member.*)

1873. Simpson, Alfred, 11 High Street, Hull; and Denmark House, Alexandra Road, St. John's Wood, near Hull.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1882. Simpson, John Harwood, Severn Tunnel Works, Portskewett, near Chepstow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C.

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 4 Clifton Park, Clifton, Bristol.

1879. Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, West Hartlepool.

1866. Smith, Edward Fisher, The Priory Offices, Dudley.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, John, Brass Foundry, Traffic Street, Derby.

1876. Smith, John, Messrs. Thomas Robinson and Son, Rochdale.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street Halifax.

1881. Smith, Robert Henry, Professor of Engineering, Sir Josiah Mason's Science College, Birmingham.

1882. Smith, Walter Parker, 15 New Broad Street, London, E.C.

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne.

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1876. Speck, Thomas Samuel, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Knoll, Fulshaw Park, Wilmslow, near Manchester.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Vulcan Tube Works, Westbromwich.

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.
1862. Stableford, William, Broadwell House, Oldbury, near Birmingham.
1869. Stabler, James, 11 Elgin Gardens, Effra Road, Brixton, London, S.W.
1880. Stafford, George, Russell Street Lace-Curtain Works, Nottingham.
1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.
1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.
1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.
1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.
1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgmorton Street, London, E.C.
1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow; and 10 Victoria Chambers, Victoria Street, Westminster, S.W.
1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.
1878. Stevenson, George Wilson, 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Silwood Park, Sunninghill, near Staines.
1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.
1851. Stewart, John, Blackwall Iron Works, Poplar, London, E.
1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1875. Stoker, Frederick William, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.
1877. Stokes, Alfred Allen, Chief Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, Bengal: (or care of Messrs. W. and H. M. Goulding, 108 Patrick Street, Cork.)
1864. Stokes, James Folliott, care of Charles P. B. Shelley, 45 Parliament Street, Westminster, S.W.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow.

1882. Sturgeon, John, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1882. Sugden, Thomas, Chadderton Iron Works, near Oldham.

1861. Sumner, William, 2 Brazennose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, Steel Company of Scotland, Newton, near Glasgow.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, 16 and 17 Exchange Buildings, Stephenson Place, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C.

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Superintending Engineer, Euphrates and Tigris Steam Navigation Company, Bussora and Bagdad: (or care of William Cole, 35 Grove Road, Regent's Park, London, N.W.)

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, Panther Lead Smelting Works, Avon Street, St. Philip's, Bristol.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1882. Taylor, Robert Henry, Spithead Forts, Stokes Bay Works, Gosport.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1876. Taylor, William Henry Osborne, Salford Villa, 12 Elm Grove, Peckham Rye, London, S.E.

1864. Tennant, Charles, M.P., The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 19 The Parade, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1857. Thompson, Robert, Victoria Chambers, Wigan; and Standish, near Wigan.

1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.

1862. Thompson, William, 116 Fenchurch Street, London, E.C.

1879. Thomson, David, 4 Cholmeley Park Villas, Highgate, London, N.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1880. Thornbery, William Henry, Jun., Corporation Chambers, 121 Colmore Row, Birmingham.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1877. Thornton, Frederic William, Hydraulic Engineering Co., Chester.

1882. Thornton, Hawthorn Robert, Engineer-in-Chief, Locomotive Department, Cape Government Railways, Cape Town.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide.

1875. Thwaites, William Henry, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1876. Trevithick, Richard Francis, The Cliff, Penzance.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1882. Turner, Thomas, "Mechanical World," Blackfriars Street, Manchester.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 11 Little Queen Street, Westminster, S.W.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1875. Unsworth, Thomas, 79 Piccadilly, Manchester.

1878. Unwin, William Cawthorne, Professor of Engineering, Royal Indian Engineering College, Cooper's Hill, Staines.

1862. Upward, Alfred, 8 Queen Anne's Gate, Westminster, S.W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of Walter Ross, 37 Lansdowne Road, Clapham, London, S.W.)

1880. Valon, William Andrew McIntosh, Engineer, Ramsgate Local Board, Hardres Street, Ramsgate.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.)

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1873. Waldenström, Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

1872. Walker, Alexander, North British Railway, Locomotive Department, Ladybank, Fifeshire.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 12 Ash Street, Southport.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin.

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 60 Queen Victoria Street, London, E.C.

1882. Ward, Thomas Henry, Messrs. Lee Howl Ward and Howl, Tipton.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1881. Warham, Richard Landor, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1882. Warsop, Henry, Corporation Gas Works, Eastcroft Works, Nottingham.

1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Member.*)

1881. Watkins, Alfred, 62 South Street, Greenwich, S.E.

1862. Watkins, Richard, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1866. Watson, Robert, Engineer, Brereton and Hayes Collieries, near Rugeley.

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford.

1878. Weatherhead, Patrick Lambert, 3 Chaussée Strasse, Berlin.

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1872. Welch, Edward John Cowling, Palace Chambers, St. Stephen's, Westminster, S.W.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, A13 Exchange Buildings, Liverpool.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

1877. Western, Charles Robert, Messrs. Western and Co., Chaddesden Works, Derby; and Chaddesden Hill, Derby.

1877. Western, Maximilian Richard, care of Messrs. Western and Sons, 35 Essex Street, Strand, London, W.C.

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, 228 Arkwright Street, Nottingham.

1867. Weston, Thomas Aldridge, care of J. C. Mewburn, 169 Fleet Street, London, E.C.

1880. Westwood, Joseph, Jun., Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.; and 39 Great Tower Street, London, E.C.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, Maple Street, Nottingham.

1867. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown, Wigtownshire.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and Hough House, Waterloo Road, Wolverhampton.

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1874. White, Henry Watkins, Chief Engineer, H.M. Dockyard, Simon's Town, Cape of Good Hope.

1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and Stancliffe, Matlock Bath; and 24 Great George Street, Westminster, S.W.

1878. Whytehead, Hugh Edward, 88 West Hill, Sydenham, London, S.E.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India.

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C.

1877. Wilkinson, Robert, Fryer Concrete Co., Antigua, West Indies.

1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 38 Parliament Street, Westminster, S.W.

1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.

1873. Williams, William Lawrence, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1870. Willman, Charles, Exchange Place, Middlesbrough.

1878. Wilson, Alexander, Messrs. Wilson Cammell and Co., Steel Works, Dronfield, near Sheffield.

1882. Wilson, Alexander Basil, Messrs. John Rowan and Sons, Duncrue Street, Belfast.

1872. Wilson, Alfred, Messrs. Tangyes' Steel Works, Soho, near Birmingham.

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1881. Wilson, John, 9 Dean's Yard, Westminster, S.W.

1863. Wilson, John Charles, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, S.E.

1857. Wilson, Robert, F.R.S.E., Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1880. Wilson, Robert, 24 Poultry, London, E.C.

1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)

1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1867. Winby, Frederick Charles, St. Stephen's Palace Chambers, 9 Bridge Street, Westminster, S.W.

1872. Winstanley, Robert, Mining Engineer, 32 St. Ann's Street, Manchester.

1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C.

1871. Withy, Edward, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1878. Wolfe, John Edward, care of G. W. Wucherer, H.B.M. Vice-Consul, Jaragua, Maceio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Wei"; care of Chinese Customs Agency, Hong Kong, China.

1878. Wolfenden, Robert, Engineer and Millwright, Shanghai, China: (or care of Frederick Degenaer, Zetland Street, Hong Kong, China.)

1882. Wolff, John Frederick, Gloucester Wagon Works, Gloucester.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1873. Woodhead, John Proctor, 54 John Dalton Street, Manchester.

1874. Worsdell, Thomas William, Locomotive Superintendent, Great Eastern Railway, Stratford, London, E.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.; and 38 Carlyle Square, King's Road, Chelsea, London, S.W.

1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester.

1881. Wrench, John Mervyn, Resident Engineer, Scinde Punjaub and Delhi Railway, Lahore, Punjaub, India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of Messrs. Malcolm Brunker and Co., 22 St. Mary Axe, London, E.C.)

1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.

1878. Wright, George Howard, Mining Engineer, 12 Trumpington Street, Cambridge.

1876. Wright, James, Messrs. Ashmore and While, Hope Iron Works, Bowesfield, Stockton-on-Tees.

1867. Wright, John Roper, Messrs. Wright Butler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Attercliffe, 42 Frederick Road, Edgbaston, Birmingham.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.

1878. Wright, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1877. Wyvill, Frederic Christopher, 33 Obern Strasse, Bielefeld, Westphalen Germany.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, Assistant Locomotive Superintendent, Northern Bengal State Railway, Saidpur, Bengal, India: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1879. Yeomans, David Maitland, American Finance Co., 5 and 7 Nassau Street, New York.

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1881. Younger, Robert, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1880. Ziffer, Ferdinand Henry, Messrs. Ziffer and Walker, 6 Exchange Street, Manchester.

ASSOCIATES.

1880. Allen, William Edgar, Well Meadow Steel Works, Sheffield.
1880. Bagshawe, Washington, Messrs. John Spencer and Sons, Newburn Steel Works, Newcastle-on-Tyne.
1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.
1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1882. Dodson, Edward, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.
1882. Drury, Robert Francis, George Street, Sheffield.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1878. Grosvenor, The Right Hon. Lord Richard De Aquila, M.P., 12 Upper Brook Street, Grosvenor Square, London, W.
1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.
1874. Hardcastle, Robert Anthony, Monk Bridge Iron Works, Leeds.
1882. Jackson, William, Kingston Cotton Mill, Hull.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, London, E.C.
1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield.
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.
1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.
1877. Render, Frederick, Crown Corn Mills, Stanley Street, Salford, Manchester,
1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.
1878. Roeckner, Carl Heinrich, 4 Royal Arcade, Newcastle-on-Tyne.
1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.
1882. Sokell, John Henry, Monk Bridge Iron Works, Leeds.
1878. Stuart, James, Professor of Mechanism in Cambridge University, Trinity College, Cambridge.
1882. Tayler, Alexander James Wallis, 63 Victoria Road, Kilburn, London, N.W.
1869. Varley, John, Farnley Iron Works, Leeds.
1875. Waslekar, Nanaji Narayan, 21 Old Boitokhana Bazar Road, Calcutta.
1878. Watson, Joseph, Attorney General's Chambers, New Court, Temple, London, E.C.

GRADUATES.

1881. Alexander, Edward Disney, care of Rev. W. Hudson, Bishopthorpe Vicarage, York.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, 22 Portsea Place, Connaught Square, London, W.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, London, S.E.

1882. Anderson, William, North Eastern Railway, Locomotive Department, York.

1878. Appleby, Charles, Jun., Messrs. Appleby Brothers, East Greenwich Works, London, S.E.

1878. Armstrong, Joseph, Great Western Railway Works, Swindon.

1872. Armstrong, Thomas, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1882. Barstow, Thomas Hulme, Assistant Engineer, Locomotive Department, Auckland Railway, Auckland, New Zealand.

1881. Beesley, David Stanley, Messrs. Stanford and Beesley, 89 Dartmouth Street, Birmingham.

1880. Benham, Percy, Messrs. Benham, 50 Wigmore Street, London, W.

1880. Birkett, Herbert, Messrs. J. and E. Hall, Iron Works, Dartford.

1882. Blundstone, Samuel Richardson, Messrs. J. J. Seekings and Co., Quay Street Iron Works, Gloucester.

1882. Bowles, Edward Wingfield, Messrs. Apps and Bagot, 433 Strand, London, W.C.

1880. Bright, Thomas Smith, Picton Villa, Carmarthen.

1878. Brooke, Arthur, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.

1880. Buckle, William Harry Ray, 18 Bootham, York.

1878. Buddicom, Harry William, Moreton Villa, Abergavenny.

1879. Burnet, Lindsay, Messrs. John Norman and Co., Keppoch Hill Engine Works, 475 New Keppoch Hill Road, Glasgow.

1881. Clench, Gordon McDakin, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dady, Jamsetjee Nesserwanjee, 10 Dady Sett House, Fort, Bombay, India.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Brown and Adams, Guild Hall Chambers, Cardiff.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1882. Hart, Norman, care of Messrs. Monteiro Hime and Co., Rio de Janeiro, Brazil: (or care of Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.)

1882. Heath, Ashton Marler, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham.

1874. Hedley, Henry, Coppa Colliery, near Mold, Flintshire.

1874. Hedley, Thomas, 13 Elm Vale, Fairfield, Liverpool.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1880. Jenkins, Rhys, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham; and 10 Launder Terrace, Grantham.

1881. Lawson, James Ibbs, New Zealand Railways, Dunedin, Otago, New Zealand.

1881. Lockyer, Norman Joseph, Manchester Sheffield and Lincolnshire Railway, Locomotive Department, Gorton, Manchester.

1879. Lowthian, George, 3 Victoria Mansions, Victoria Street, Westminster, S.W.

1881. Macdonald, Ranald Mackintosh, New Zealand Railways, Christchurch, New Zealand.

1878. Mannock, Thomas, Messrs. Higginbottom and Mannock, Crown Iron Works, Hyde Road, West Gorton, Manchester.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1882. Martindale, Warine Ben Hay, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1882. Maw, Matthew Henry, Assistant Engineer, Public Works Department, India; 22 Station Road, South Norwood, London, S.E.

1882. McLaren, Raynes Lauder, 7 The Avenue, Blackheath, London, S.E.

1881. Milles, Robert Sydney, St. Margaret's, Staplehurst.

1867. Mitchell, John, Swaithe Colliery, Barnsley.

1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1872. Napier, Robert Twentyman, Yoker, Dumbartonshire.

1882. Nettlefold, Hugh, Screw Works, Broad Street, Birmingham.

1878. Newall, John Walker, Forest Hall, Ongar, Essex.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1881. Norris, Moraston Ormerod, Assistant Engineer, Public Works Department, Madras: care of Messrs. Arbuthnot and Co., Madras.

1881. Oswell, William St. John, Frankton House, Oswestry.

1876. Owen, George Charles Mickleburgh, Banbury and Cheltenham Direct Railway, High Street, Chipping Norton: (or care of George Owen, Park Issa, Oswestry.)

1880. Paterson, Walter Saunders, London Brighton and South Coast Railway, Locomotive Department, London Bridge, London, S.E.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1879. Phillips, Robert Edward, 32 Selby Road, Anerley, London, S.E.

1881. Rogers, Philip Powys, Assistant Engineer, Warda Coal State Railway, Warora, Central Provinces, India.

1882. Sanchez, Juan Emilio, care of Matteo Clark, 12 Great St. Helen's, London, E.C.

1882. Scott, Charles Herbert, Messrs. W. and J. Galloway, Knott Mill Iron Works, Manchester.

1881. Scott, Ernest, Messrs. R. and W. Hawthorn, Newcastle-on-Tyne.

1875. Sheppard, Herbert Gurney, 89 Westbourne Terrace, Hyde Park, London, W.

1879. Solly, Arthur John, Heathfield, Congleton.

1877. Spielmann, Marion Harry, 16 Porchester Terrace, Hyde Park, London, W.

1874. Taylor, Arthur, Pontgibaud Lead Works, Puy de Dôme, France; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.

1882. Wailes, George Herbert, St. Andrews, Watford, Herts.

1875. Walker, Arthur Henry, Guild Hall Chambers, Cardiff.

1881. Walkinshaw, Frank, Hartley Grange, Winchfield.

1880. Weymouth, Francis Marten, Mill Hill, London, N.W.

1877. Whitelock, William Thomas Grant, Bowling Iron Works, near Bradford.

1879. Wood, Edward Walter Naylor, 7 Theresa Terrace, Hammersmith, London, W.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.; and 27 Alma Road, St. Paul's Road, Canonbury, London, N.

1882. Woollcombe, Reginald, Assistant Engineer, Public Works Department, India; care of Messrs. King King and Co., Bombay.

1880. York, Francis Colin, care of Messrs. Samuel York and Co., Snow Hill, Wolverhampton.

Institution of Mechanical Engineers.

MEMOIRS

OF MEMBERS DECEASED IN 1881.

SAMUEL BAKER was born at Pudsey, near Leeds, in 1822. He came to Liverpool in 1842, and worked as a journeyman engineer, principally with the late firm of Mather and Dicksons, and with Messrs. Fawcett Preston and Co. By the latter he was appointed chief engineer of the steamer "Nile," which he took out in 1848 to Egypt, and there entered the service of the Pasha of Egypt. In 1854 he returned to Liverpool, and commenced business as engineer in Oil Street; this business he carried on until his death, which took place at Bootle on 19th December 1881. He became a Member of the Institution in 1866.

EDWARD TAYLOR BELLHOUSE was born at Manchester on 10th October 1816, being the eldest son of David Bellhouse, whose family originally belonged to Yorkshire. He was apprenticed to Messrs. Wren and Bennett, where he remained for some six and a-half years, and where he acquired a thorough knowledge of practical engineering. He then worked for about a year as a journeyman millwright at the Caloa Mills, and at the St. Helen's Union Plate Glass Works; and next spent a year as a journeyman at Sir William Fairbairn's works in the Isle of Dogs. The following year, the last of his actual workshop life, he passed in the employ of the Liverpool Grand Junction Railway. On 1st July 1842 he started the firm of E. T. Bellhouse and Co., which has carried on a prosperous business for the last forty years at the Eagle Foundry, Hunt Street, Manchester. It was just at a time when all branches of engineering were making large strides that the new firm was started; it rapidly became prosperous, and in a few years grew to be one of the principal

engineering establishments in Manchester. Large contracts were undertaken for the English and for foreign Governments, as well as for private companies. Among these may be mentioned the gas works for Buenos Ayres, Pernambuco, and Athens. Mr. Bellhouse undertook the erection of many large bridges for various railways; and the whole of the stations required for the Arequipa Railway were constructed by him. Another branch of engineering in which he took a great interest was the construction of iron buildings. He made and erected many custom-houses of iron; among others, that for Payta, Peru—a building unique of its kind. Within Manchester he did a large amount of work, both for the corporation and for others. The construction of large roofs, and the general ironwork in connection with the erection of buildings, constituted the principal part of his Manchester business, although he did a large amount of hydraulic work, having among other things designed and made the hydraulic lifts &c. in the new City Hall, Manchester. Apart from business he took an interest in every institution which tended to the benefit of his fellow-citizens, and showed especially an active desire to better the position of his workmen; for the latter purpose an extensive scientific library was formed at the Eagle Foundry. He was connected with the formation of the Athenæum, was president of the Mechanics' Institute, and a director of the Royal Institution of Manchester; and in many other ways he gave all the aid in his power towards benefiting the social life of his native town. After a life of hard work and disinterested generosity, the ravages of time and over-work began at length to be felt by a constitution which was not naturally of the strongest. Finding himself in failing health, he removed to Southport in hopes of regaining his strength; but on 13th October 1881 he died there at the age of sixty-five. He became a Member of the Institution in 1857.

ROBERT CALVERT CLAPHAM, of Earsdon House near Newcastle-on-Tyne, was born at Newcastle on 15th September 1823, and died very suddenly at Winchelsea on 22nd December 1881, aged fifty-eight. He was the son of Anthony Clapham, who was a pioneer in establishing the soda and alkali works on the banks of the Tyne,

which have since been developed into such an important branch of industry. He commenced his business life by assisting his father in the chemical works, and subsequently held appointments as manager in the Walker Alkali Works, and in several works of a similar character; but always found time to devote a great deal of his leisure to the cause of science. When the British Association met at Newcastle in 1863 he was one of the local secretaries, and by his energy and industry assisted very much in the success of the meeting. He was principally instrumental in establishing in 1868 the Newcastle Chemical Society, of which he was elected president in 1878, and to which he contributed several valuable papers. He was joint author with Mr. James C. Stevenson, M.P., and the late Dr. Thomas Richardson, of an article on the chemical manufactures of the northern district, which was included in the volume entitled "The industrial resources of the Tyne, Wear, and Tees," published in 1868; and was also the author of the article on Soda in "Chemistry as applied to arts and manufactures." He was president for one year of the northern Mechanics' Institutes Association, and was a director of the Newcastle Chemical Works, of Messrs. John Abbot and Co., and of the Tyne Steam Shipping Company. For twenty-one years he was senior honorary secretary of the Newcastle Literary and Philosophical Society. During the recent visit to Newcastle of the Institution of Mechanical Engineers he was an active member of the Local Committee. He became a Member of the Institution in 1869, and was a Fellow of the Chemical Society.

William Clay was born in Liverpool on 15th May 1823, and died there on 28th February 1881, in the fifty-eighth year of his age. On leaving school he went into an ironworks near Glasgow, where he became manager at a very early age. When the works were closed by the owner he took to mercantile pursuits for a time. These however were not in accordance with his taste, which was more of a mechanical and scientific turn, and soon developed itself; for in 1848 he devised a method of rolling taper bars, and offered his invention to Mr. W. J. Horsfall, of the Mersey Forge, Liverpool. The invention was adopted, and he was asked to assume the management of the

works, which at that time were not financially successful. Among the various improvements there effected by him was the introduction of a night shift, the works having previously been kept going during the day only; the turn-out was thereby doubled within a year, and the following year saw it again doubled, with the realisation of a profit for the first time for many years. It was from his designs and under his superintendence that about this time the so-called "Monstre" gun, the largest piece of wrought-iron ordnance then in existence, was forged, bored out to the calibre of 13 in., and completely finished. It weighed 22 tons, and threw a projectile of 300 lbs. to a distance of 5 miles, which was thought a great achievement in those days, though of course eclipsed by modern guns. It was presented to the Government by Mr. Horsfall, and after being severely tested by the Ordnance select committee, was finally mounted at Tilbury Fort. Shortly after Mr. Horsfall's death Mr. Clay became partner in the works, the value of which had been doubled from the profit realised under his management, without any extra capital having been raised; while a working capital had also been set aside equal to their original value. He was the first to introduce in this country the manufacture of puddled steel on a large scale, and turned out large quantities of this material in various forms. The plates for the steamer built for Dr. Livingstone's expedition in Central Africa were manufactured by him of this steel, their weight being only 4 lbs. per square foot. The whole of the new works, by which the Mersey Forge was gradually enlarged to the magnitude of a leading establishment, including the laying-out of the ground, the roofs, and the massive machinery, were designed by him. In 1864, the works having been transferred to a company, he ceased to have the control, and very soon terminated his connection with them. In conjunction with Mr. C. A. Inman and Captain McNeile he then established the Birkenhead Forge, where his abilities were similarly successful. He was looked upon as one of the first ironmasters of the day; and his unbroken success in turning out the heaviest marine shafts and other forgings was owing in no small degree to the fact that his men had the most perfect confidence in him. He could take his place, and often did so, at the smithy, the puddling furnace, the shingling hammer, &c.; and

showed that he was as well able to execute with his own hand as to design. He was very frequently engaged as arbitrator in disputes in the iron trade, his intimate knowledge of all its branches making his opinion of much value. While at the Mersey Forge he formed a volunteer artillery corps, composed at first almost solely of those employed there; under his command it grew to the strength of 950 men, and he attained the highest rank that could be reached among the volunteers, namely that of Lieut.-Colonel Commandant, which he resigned only a few months before his death, after having retained the command of the corps for twenty years. He became a Member of the Institution in 1859, and was for some years a member of the Council, and also a Vice-President. In 1872 he contributed a paper on a hollow turning tool, cooled with water, for turning metals at increased speed. In the same year he was a most energetic and successful Chairman of the Local Committee for the Summer Meeting of the Institution in Liverpool.

ARTHUR LOFT DOSSOR, son of Mr. James Dossor, surgeon, of Hull, was born there on 4th July 1843. After receiving his preliminary education at Wesley College, Sheffield, and subsequently at Darmstadt, he was apprenticed to the firm of Martin Samuelson and Co., iron shipbuilders and engineers, Hull, with whom he remained for a term of six years. He afterwards went to London, where he was engaged by Messrs. Fothergill and Samuelson, consulting engineers, for two or three years. Subsequently he became the London representative of Messrs. Wheatley Kirk Price and Goulty, consulting engineers &c., of Manchester and London. In the autumn of 1880, on account of failing health, he went to Lisbon for a three months' rest, hoping that the climate, which had previously done him good, would again restore him to strength. This expectation was not realised, and he died there on 11th February 1881, in the thirty-eighth year of his age. He became a Member of the Institution in 1877.

JAMES FLETCHER was born at Birtles near Manchester in 1806, and was apprenticed at an early age to Mr. Thomas Smith, millwright,

Burnley. On the expiration of his apprenticeship, he was employed for some years by Mr. Charles Dyer, Manchester, and afterwards by Messrs. Sharp Stewart and Co. Subsequently he took the management of the works of Messrs. William Collier and Co. in Greengate, Salford, and became in 1853 a partner in the firm; and on the death of Mr. Collier in 1863 he became sole proprietor. In 1843 he introduced improvements in the "going-in" and "winding-on" motions of self-acting mules, and a novel mode of so connecting the copping and winding-on motions that the one should control the other. In 1845 he improved what is known as the "presser flyer," and employed malleable cast-iron as a material for flyers. Jointly with Mr. Thomas Fuller, one of the partners in the firm of Collier and Co., he introduced in 1849 a number of improved machine-tools; including a double-acting sliding and surfacing lathe, an apparatus for boring locomotive cylinders in their places, and a tool for planing locomotive valve-faces in their places. He also made various improvements in slotting and shaping machines, including the use of elliptical gearing to give a quick return. With Mr. J. W. Fuller, another of the partners, he made in 1861 an improved planing machine, and in 1862 further improvements in rolling, bending, and planing metals. As a practical engineer his advice was frequently sought; and he was a director of several large iron and engineering companies in the neighbourhood of Manchester, as well as in Glasgow and Middlesbrough. In consequence of failing health he retired from business in 1875; and his death took place on 23rd March 1881, in the seventy-fifth year of his age, after a long and painful illness. He became a Member of the Institution in 1857, and at the Glasgow meeting in 1864 contributed an elaborate paper on Heavy Tools for general engineering and iron shipbuilding work.

JOHN FRASER was born on 28th July 1819 at Linlithgow, Scotland, being the eldest son of Mr. James Fraser, architect, of Manchester, who was at that time engaged in the construction of extensive dock and other works at Charlestown on the Forth, for the Earl of Elgin. After completing his pupilage under Mr. Thomas Buck, he was engaged under Mr. Edward Woods as Resident

Engineer, having charge of works in the construction of the Salford Junction Railway, Manchester; and subsequently from 1846 to 1856 under Mr., now Sir John Hawkshaw, as Resident Engineer in charge of the works in the construction of the Huddersfield & Sheffield, the Leeds Bradford & Halifax, and the Bradford Wakefield & Leeds Railways, and of their branches, in the West Riding of Yorkshire. During the following period of twenty-five years he was actively engaged in practice on his own account, as a civil engineer in Leeds. He successfully carried out various works, some of which were of considerable magnitude; such as the construction of numerous extensions for the lines above mentioned, and of the following new and important railways in Yorkshire:—the Ossett, Batley, Adwalton, and Gildersome branch lines; the joint West Riding and Grimsby Railways (from Wakefield to Barnby Don and Doncaster); the joint railway to Methley; the joint Halifax and Ovenden Junction Railway; the branch to the Lancashire and Yorkshire Railway at Bradford; the Bradford Eccleshill & Idle, and the Idle & Shipley Railways; the Ossett & Dewsbury, the Batley & Dewsbury, and the Leeds Castleford & Pontefract Junction Railways; the Bradford & Thornton Railway; and the southern section from Thornton to Halifax of the Halifax Thornton & Keighley Railway. He also completed recently several railways in Nottinghamshire and Leicestershire; such as the line from Newark to Melton and Tilton, about 40 miles in length, and a further section of about 11 miles from Tilton to Leicester, which was nearly completed at the time of his death. The heavy works on the northern section from Thornton to Keighley of the Halifax Thornton & Keighley Railway were commenced and partly carried out by him, and are now being completed by his sons. Amongst his other works may be mentioned the new North Bridge at Halifax. He was well known in parliamentary committee rooms, in which he had a long experience; and as a civil engineer was deservedly held in high esteem for his professional ability and integrity. He died suddenly on 24th September 1881, at his residence, Grove House, Headingley, Leeds, in the sixty-third year of his age. He became a Member of the Institution in 1859.

James Nixon Grainger was born at Newport, Isle of Wight, in 1847, and died there on 14th March 1881, at the age of thirty-four. After being educated at Greenwich School, he was placed in Portsmouth Dockyard, and was sent thence by the authorities to the South Kensington School of Art. He then obtained an engineering appointment in the Public Works Department of India, at Chepank, Madras. There he remained eleven years, receiving promotion several times, and returned home in 1878. He became a Member of the Institution in 1869.

Frederic Groom Grice was born at Westbromwich on 2nd November 1829, and died at Torquay on 18th August 1881, in the fifty-second year of his age. He was for many years connected with the business of his father's firm, Messrs. Weston and Grice, Stour Valley Works, Westbromwich, and Cwmbran Iron Works near Newport, Monmouthshire; during which time he invented several valuable machines, used in the manufacture of bolts and nuts. After the amalgamation of the above firm with the Patent Nut and Bolt Company, he remained for many years as Managing Director of the Cwmbran Works. He became a Member of the Institution in 1860.

John Head was born at Ipswich on 8th February 1832, and served his apprenticeship there in the engineering works of Messrs. Ransomes and May, afterwards Ransomes and Sims; by whom, after working for a time in Mr. Scott Russell's iron shipbuilding yard at Millwall, he was entrusted with the erection of some large pumping engines at Warsaw. This service, rendered difficult by the political complications preceding the outbreak of the Crimean war, was volunteered for by him before the age of twenty, and ably fulfilled. For some years afterwards he was manager of metallurgical works at the same city. In 1864 he became a partner with Messrs. Ransomes and Sims; and introduced several inventions, of which the most successful was the device for burning straw in portable engines. An affection of the throat, from which he had latterly suffered, became more persistent in 1880, and led to his wintering at the Cape; but the change did not produce the desired benefit, and shortly after his

return he died at Ipswich on 19th May 1881, at the age of forty-nine. He became a Member of the Institution in 1860.

Matthew Hill Loam was born at Crowan near Camborne, Cornwall, in 1817; and died at his residence in Nottingham on 20th September 1881. After serving as pupil and assistant to his father, who was entrusted with the erection in 1847 of the celebrated compound Cornish pumping engines constructed by Messrs. Harvey of Hayle for draining Haerlem Lake, he was appointed in 1851 resident engineer to the Nottingham Gas and Water Works. That position he continued to hold, carrying out successfully the large and important extensions of both these works under Mr. T. Hawksley, until they were taken over by the Corporation on 1st May 1874, when he relinquished his connection with the water works, and became assistant engineer to the Corporation gas department, retaining this post till his death. He became a Member of the Institution in 1863.

Henry Merryweather was born at Wandsworth on 6th August 1846, and served his apprenticeship with his father's firm, in which he became a partner in 1872. He effected various improvements in the design and construction of steam and hand fire-engines, including a tubular boiler for getting up steam very quickly. In the development and application of tramway locomotives his attention was specially engaged; and in 1872 he conducted the trials at Brompton of the combined steam tramcar built by his firm for Mr. Grantham. He gave evidence in 1877 before the parliamentary committee appointed to enquire into the possibility of employing steam power for the propulsion of tramcars; and conducted in their presence some highly successful experiments at Leytonstone, with one of the detached tramway locomotives constructed by his firm. His death took place at Brighton, from an attack of typhoid fever, on 29th December 1881, at the age of thirty-five. He became a Member of the Institution in 1877.

Joseph Henry Nettlefold was born in London in 1827, and was educated at a private academy in the neighbourhood; he gave early

proof of that mastery in mathematics which so distinguished him in after life. After leaving school he joined the hardware business conducted in London by his father and brother; and at intervals went to Birmingham, to acquire a knowledge of the business established there many years before by his father for the manufacture of the celebrated gimlet-pointed wood-screw of his invention. These visits became more and more frequent, until at length he took up his residence in Birmingham, and from that time assumed the management of the vast manufacturing enterprise with which his name is so intimately associated. He greatly extended the business, in conjunction with Mr. Chamberlain, the present President of the Board of Trade; on whose retirement he again took the entire management. In 1879 this business, to which had by that time been added collieries, ironworks, and the manufacture of wire, was combined with several smaller concerns of a kindred character, into a company under the name of Nettlefolds Limited. The organisation and consolidation of the various businesses into one concern was entirely his work; and perhaps in no other case was his great administrative ability so clearly shown. Without having had any special mechanical training, his talents enabled him to acquire the engineering skill displayed in the laying out and direction of the different works which he started; while his practical experience and judgment enabled him to adopt any changes which constituted real improvements, and to discard what were so in appearance only. On his invitation, the large works at Smethwick for the manufacture of wood screws were visited by the Members of the Institution at the Summer Meeting at Birmingham in 1876. His death took place at his Highland residence, Allean House, near Pitlochry, on 22nd November 1881, after an apoplectic seizure, at the age of fifty-four. He became a Member of the Institution in 1860.

William Owen was born at Rotherham on 23rd March 1810; and in 1823 was apprenticed to the pattern-making business with Messrs. Sandford and Yates, Phœnix Foundry, in that town. Subsequently for some years he acted as traveller to the firm, in which he became a partner in 1832, and then took the management

of the forge and wrought-iron department. To the manufacture of large forgings for marine engines, which had been commenced there in 1831, was added in 1836 that of railway wheels and axles. In 1838 the firm became Messrs. Sandford and Owen, and in 1852 Mr. Owen became sole proprietor of the works. From 1863, having previously disposed of these works, he carried on the manufacture of stove-grates, kitchen-ranges, and general castings, at the Wheathill Foundry. He invented several valuable improvements in the manufacture of solid wrought-iron wheels and tyres; and was for some years chairman of the Midland Wagon Company, formed by himself and others for purchasing and hiring out railway wagons. His death took place at his residence, Clifton House, Rotherham, on 20th January 1881, in the seventy-first year of his age. He was one of the original Members of the Institution upon its formation in 1847.

Edward Antoine Sacré was born in London on 8th October 1838, and after being educated there and in Belgium was articled to Mr. Archibald Sturrock, locomotive superintendent of the Great Northern Railway, by whom he was frequently employed in making experiments as to consumption of fuel and water in locomotives, and also as to the general loading of trains, particularly for goods and mineral traffic. He next became assistant to Mr. Budge, district locomotive superintendent of the Great Northern Railway at King's Cross; and on the opening of the East Kent Railway, now the London Chatham and Dover, he was appointed to the charge of the locomotive department. Shortly afterwards he went to Australia, where he became actively engaged in responsible positions in connection with railway working, amongst others as locomotive and traffic superintendent of the St. Kilda and Brighton Railway. For some time he was contractor's engineer for the construction of a large portion of the Picton and Ballarat Railway and other lines. After being seven years in Australia he returned to London, and joined Mr. H. W. Hunt as partner in the engineering firm of Hunt and Sacré, in which he continued to the time of his death. Latterly he was also deputy chairman of the Felixstowe Railway and Dock. He had a varied and extensive experience in the design and construction of

rolling stock and all kinds of machinery; and had frequently visited the United States and Canada, and most European countries. He died in London on 26th October 1881, at the age of forty-three, after a lingering illness. He became a Member of the Institution in 1868.

WILLIAM SMITH was born in Paisley in January 1819. After leaving school he spent two years in a lawyer's office, and then went into his father's works at Paisley, to learn the business of millwright and engineer. His father, who had a considerable reputation as a maker of agricultural, corn, flour and saw-mill machinery, died early in 1838; and Mr. Smith, though only nineteen years of age, joined his brother, Mr. Alexander Smith, in taking up the business under the firm of A. & W. Smith & Co. Owing to the increased demand for agricultural machinery about 1840, the business extended very rapidly; and in 1855 the firm erected larger works in Glasgow, to give greater facilities in manufacture. They then added to their business the manufacture of sugar-making machinery. In 1861 Mr. Smith went to Mauritius, with the view of getting a more perfect knowledge of the machinery required on the sugar estates; and the business in this department largely increased in consequence. In 1878 he visited the West Indies with a similar view, and with much success. In 1880 he left the firm, and commenced business with two of his sons under the style of William Smith & Sons; and was just erecting new works in Partick, Glasgow, when his death took place very unexpectedly and suddenly on 17th March 1881. He took a great interest in the Trades House of Glasgow, and was elected to the office of Deacon Convener in 1874, this being the highest honour the Trades House can confer upon any member. He became a Member of the Institution in 1866.

THOMAS SPITTLE was born at Netherton near Dudley on 5th January 1806; and died at his residence, Cambrian House, Maindee, near Newport, Monmouthshire, on 19th November 1881, in his seventy-sixth year. While a young man he made his name known in connection with foundry work at Abersychan and other places in that district; and in 1849 he established the Cambrian Foundry and

Engineering Works at Newport, which, through his perseverance and shrewd business qualities, are now amongst the largest works in the district, and have given continuous employment to a great number of workmen from the commencement. A few years ago he made a very spirited start in iron shipbuilding, an industry new to South Wales; but the effort, proving rather in advance of the time, was discontinued after the construction of two ships; and the shipyard was utilised for the building of locomotives and for ordinary engineering work. He was also associated in a colliery undertaking; but it was foundry work to which his energies were chiefly directed, and of which he was so thorough a master, achieving a high reputation for quality and workmanship in his productions. One of these was a convenient cask stand, made of three simple castings with a toothed segment and worm, for gradually tilting barrels as they become empty. He became a Member of the Institution in 1864.

JOHN TAYLOR was born at Holwell, near Tavistock, on 11th August 1808, and received his education at the Charterhouse, and subsequently at Manchester College, York. After acquiring much practical knowledge in the mines under the management of his father, Mr. John Taylor, he was sent with his brother Richard to Germany, and spent nearly the whole of the year 1828 in visiting all the principal mines of that country and of Austria. Soon after his return Mr. John Taylor was appointed by his father to a position in the management of lead mines in Flintshire, which were then in great activity. Eventually he took the chief management of the great Mold mines and of the Halkyn mines in that county; and also took an active part in the opening out of many of the long-abandoned mines of Cardiganshire. During the same period he was also occupied with the Grassington mines in Yorkshire, the great mine of Minera in Denbighshire, and the Allport mines in Derbyshire, where he employed a water-pressure engine of enormous power, designed by the late Mr. Darlington. In 1845 he came to London to join his father as a partner. In 1853 the management of the Linares lead mines in the province of Andalusia, Spain, came into the hands of Messrs. John Taylor and Son; and this led subsequently to the

formation of the Fortuna and Alamillos companies for working other lead mines in the same district. The discovery of silver at Hien del Encina, in the province of Guadalaxara, Spain, engaged the attention of the firm, and they formed the Bella Raquel Mining Company for working these ores. A leading part was taken by Mr. John Taylor in the planning of the Fabrica la Constante for that company. In this establishment the Freiberg process of amalgamation was carried out with great success, with the advantage of improved English machinery. At the same time he developed the mines of Palhal and Carvalhal in Portugal, yielding argentiferous copper ores together with ores of cobalt and nickel. The firm had undertakings also in Central America, in Canada, in Western Africa, and at the Cape of Good Hope. In 1853 Mr. John Taylor made an inspection of the argentiferous lead mines of Pontgibaud, Puy de Dôme, France, which led to an Anglo-French company being formed for working them: Messrs. John and Richard Taylor (the latter having now joined the firm) conducting the entire practical management of the extensive mines and smelting works. In addition to those mentioned, the firm were connected with many other metalliferous mines of almost every description. Mr. John Taylor's death took place at St. Albans on 20th April 1881, at the age of seventy-two. He became a Member of the Institution in 1862.

William Yule was born in Glasgow in 1823, and died in St. Petersburg on 13th January 1881. When a very young man he worked as a puddler and roll turner at the Calderbank Iron Works, Lanarkshire. Thence he was taken in 1840 to turn the rolls for the Mossend Iron Works, Lanarkshire, then being erected. In 1846 he was engaged to go to St. Petersburg, to the rolling mills in the large works of Mr. F. Baird. There he continued in charge of the malleable iron department till 1865, when he retired to Scotland for two years. In 1867 he returned to St. Petersburg, where he was well known as a mechanical engineer, and began as an ironfounder and engineer on his own account; that business he carried on successfully till 1878, when he finally retired. He became a Member of the Institution in 1861.

Institution of Mechanical Engineers.

PROCEEDINGS.

January 1882.

The Thirty-fifth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, 26th January, 1882, at Half-past Seven o'clock p.m.; Edward A. Cowper, Esq., Retiring President, in the chair, succeeded by Percy G. B. Westmacott, Esq., President elected at the Meeting.

The Minutes of the last Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following New Members, Associates, and Graduates were found to be duly elected:—

MEMBERS.

John Barber,	Leeds.
Frank Beattie,	Birmingham.
Joseph Phillips Bedson,	Manchester.
Enrique Budge,	Valparaiso.
Charles Simmons Church,	Barranquilla.
William Denny, F.R.S.E.,	Dumbarton.
Victor Isidore Feeny,	London.
David Hardman Fletcher,	Manchester.
David Moncur Forbes,	Calcutta.
William George London Stuart Forbes,	Calcutta.
John Reed Fothergill,	West Hartlepool.
John William Howard,	London.
Charles Malcolm Johnson,	Devonport.

Auguste Léon, ...	Paris.
Walter Sandell Mappin, ...	London.
James Murray Molesworth, . . .	Tientsin, China.
John Sinclair Pirrie, ...	Bombay.
Ernest Charles Antoine Presser, .	Madrid.
Thomas Sugden, ...	Oldham.
Hawthorn Robert Thornton, . . .	Cape Town.
Edwin Wardle, ...	Leeds.
Herbert Rushton Yates, ...	Pontiac, Michigan.

ASSOCIATES.

Edward Dodson, ...	Sheffield.
George John Miller Ridehalgh, . .	Ulverston.

GRADUATES.

Robert Lancelot Allgood, ...	London.
Thomas Hulme Barstow, ...	New Zealand.
Norman Hart, ...	Newcastle-on-Tyne.
Ashton Marler Heath, ...	Manchester.
Matthew Henry Maw, ...	Brighton.
Charles Herbert Scott, ...	Manchester.
Reginald Woollcombe, ...	Swindon.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF COUNCIL.

1882.

The Council have pleasure in laying the following Annual Report before the Meeting, on this occasion of the Thirty-fifth Anniversary of the Institution.

At the end of the year 1881 the total number of names of Members of all classes on the roll of the Institution was 1276, as compared with 1210 at the corresponding period of the previous year. The increase arises as follows:—there were elected within

the year 109 Members of all classes; there were lost from the register by deceases 10 names of all classes, and by resignation or removal 33 names of all classes. This effective increase of 66 is exceedingly satisfactory, being considerably in excess of that of last year, and much above the average yearly increase of the Institution.

The following Deceases of Members of the Institution have occurred during the past year:—

SAMUEL BAKER,	Liverpool.
EDWARD TAYLOR BELLHOUSE,	Manchester.
ROBERT CALVERT CLAPHAM,	Newcastle-on-Tyne.
WILLIAM CLAY,	Liverpool.
ARTHUR LOFT DOSSOR,	London.
JAMES FLETCHER,	Manchester.
JOHN FRASER,	Leeds.
JAMES NIXON GRAINGER,	Newport, I. of W.
FREDERIC GROOM GRICE,	Westbromwich.
JOHN HEAD,	Ipswich.
MATTHEW HILL LOAM,	Nottingham.
HENRY MERRYWEATHER,	London.
JOSEPH HENRY NETTLEFOLD,	Birmingham.
WILLIAM OWEN,	Rotherham.
EDWARD ANTOINE SACRÉ,	London.
WILLIAM SMITH,	Glasgow.
THOMAS SPITTLE,	Newport, Mon.
JOHN TAYLOR,	London.
WILLIAM YULE,	Glasgow.

The following gentlemen have resigned their Membership in the Institution during the past year:—

WILLIAM LAWSON AUSTIN,	Sheffield.
SAMUEL BAILEY,	Birmingham.
CHARLES BINNS,	Clay Cross.
WILLIAM BLINKHORN (Associate),	St. Helen's.
GEORGES BOISTEL,	Paris.
JOSEPH CABRY,	Newcastle-on-Tyne.
THOMAS FLETCHER CHAPPÉ DE LÉONVAL,	London.
JOHN CROSSLEY (Associate),	St. Helen's.
GEORGE CROW,	Newcastle-on-Tyne.
JOHN PUNSHON DENTON,	Stokesley.

John Sharp Wilbraham Edmunds (Graduate), . . Birmingham.
Arthur Firth, ... Leeds.
Charles Edouard Frossard (Graduate), ... Gloucester.
Joseph Edward Harrison, ... Dudley.
George Frederick Lyndon, ... Birmingham.
George Eastlake Thoms, ... Wolverhampton.
William Wainwright, ... Derby.
Hubert August Otto Weiss, ... Charlton.
John Turner Wright, ... Birmingham.

The following gentlemen have ceased to be Members of the Institution during the past year :—

Thomas Carrington, ... Sheffield.
John Albert Reinhold Hildebrandt, ... Manchester.
Henry Walker Hill, ... Nottingham.
James Hurman (Associate), ... Cardiff.
Samuel W. Linsley, ... South Shields.
Charles Spencer Rolfe, ... London.
John Sanderson, ... Wigton.
George Lamb Scott, ... Manchester.
William Smethurst, ... Wigan.
Bernard Peard Walker, ... Birmingham.
George Arthur Waller, ... Dublin.
James Whitham, ... Leeds.

The Accounts for the year 1881, having been passed by the Finance Committee, and having been audited by Messrs. Robert A. McLean & Co., Public Accountants, are now submitted to the Members (*see Appendix I.* pp. 22–23). It will be seen that the receipts for the year have been £4248 4*s.* 7*d.*, while the expenditure has been £3773 8*s.* 8*d.*, showing a balance of receipts over expenditure of £474 15*s.* 11*d.* A Balance Sheet is also appended, showing the financial position of the Institution at the end of the year to be thoroughly satisfactory. It will be seen that the total investments and other assets amounted to £13,635 1*s.* 11*d.*, and that the liabilities were *nil*, the capital of the Institution at the end of the year being therefore £13,635 1*s.* 11*d.* The greater part of this, as will be seen, is invested in Four per cent. Railway Debenture Stocks, registered in the name of the Institution, including the sum of £349 11*s.* 3*d.* invested during the year.

With regard to the question of Experimental Research, a paper by Professor Kennedy, embodying the results of his numerous experiments on Riveted Joints, made for the Committee, was read and discussed at the April Meeting; and has since been published in the Proceedings, accompanied by an exposition of the theory of the subject, by Baron Clauzel, of Toulon—a Table of existing practice, compiled by Mr. R. H. Tweddell—and the First Report of the Committee, on the past history of the question, prepared by Professor W. C. Unwin. The Council feel that the thanks of the Institution are due to the above-named gentlemen, and also to the Landore Siemens-Steel Co., the Barrow Steel Co., and Messrs. John Penn and Sons, for the valuable assistance given by them in various ways towards the elucidation of this important subject. A report by Professor Kennedy, on the results of a series of experiments on thicker plates, has been published in the October number of the Proceedings, now in the hands of the Members; and it will be found that these fully confirm the conclusions drawn from the previous experiments. As a practical result it may be stated that actual single-riveted lap-joints in steel, designed on the basis of these experiments, have shown a proportional strength of 63·7 per cent. for $\frac{3}{8}$-in. plates, and 53·0 per cent. for $\frac{3}{4}$-in. plates: whereas the average of the Table of actual practice for iron plates, calculated under the most favourable conditions, is 55·1 for $\frac{3}{8}$-in. plates, and 46·8 for $\frac{3}{4}$-in. plates. Supposing the proportions of that Table to be adhered to for steel plates, the advantage on the side of the proportions adopted by the Committee would be much greater than the above. The Committee are now taking steps to extend their researches to double-riveted joints, and to butt-joints, for both thin and thick plates.

The last number of Proceedings also contains a report by Professor F. A. Abel, C.B., F.R.S., on experiments which he has kindly conducted for the Committee on the Hardening &c. of Steel, and which seem to throw much light on this difficult subject. These experiments will be repeated and extended during the present year, still under the guidance of Professor Abel, to whom the Council feel that the best thanks of the Institution are justly due. The

thanks of the Institution are also due to Professor W. Chandler Roberts, F.R.S., for his Note upon experiments made by him, to decide the question of the influence which the occlusion of gases may have upon the hardening of steel.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. Feeling the great desirability of enlarging and improving the Library, the Council again invite the Members to make donations of books, original pamphlets, or reports, and in particular of the records of any experiments or researches made by themselves or their friends.

(*For List of Donations see Appendix II.* p. 24.)

The Meetings held in 1881 were the Annual General Meeting and the Spring Meeting, both in London, and lasting two days each; the Summer Meeting of three days at Newcastle-on-Tyne; and the Autumn Meeting at Manchester. Thus eight days in all were devoted to the reading and discussion of Papers, the list of which, as published in the Proceedings, is as follows:—

On Harvesting Machinery; by Mr. Ernest Samuelson.

On the Various modes of Transmitting Power to a distance; by M. Arthur Achard.

On Machines for producing Cold Air; by Mr. T. B. Lightfoot.

On Stone-Dressing Machinery; by Mr. J. Dickinson Brunton and Mr. F. Trier.

On the Farquhar Filtering Apparatus; by Mr. Henry Chapman.

On Riveting, with special reference to Ship-work; by M. le Baron G. Clauzel.

Results of Experiments on Riveted Joints, made for the Institution of Mechanical Engineers; by Professor Alex. B. W. Kennedy.

Rules of Practice for Iron Riveted Joints; by Mr. R. H. Tweddell.

First Report of the Committee on Form of Riveted Joints; Professor W. Cawthorne Unwin, Reporter.

On Thrashing Machines; by Mr. W. Worby Beaumont.

On the Tyne, as connected with the History of Engineering; by Mr. I. Lowthian Bell, F.R.S.

On the Progress and Development of the Marine Engine; by Mr. F. C. Marshall.

On Printing Machinery; by Mr. John Jameson.

On some recent improvements in Lead Processes; by Mr. Norman C. Cookson.

On a Feed-Water Heater and Filter for Stationary and Locomotive Boilers; by Mr. George S. Strong.

On Iron and Steel as Constructive Materials for Ships; by Mr. John Price.

On Slipways; by Mr. William Boyd.

On Bessemer Steel Plant, with special reference to the Erimus Works; by Mr. C. J. Copeland.

On Compressed-Air Engines for Tramways; by Mr. W. D. Scott-Moncrieff.

First Report of the Committee on the Hardening, Tempering, and Annealing of Steel; Mr. William Anderson, Reporter.

Hardening &c. of Steel, Results of preliminary Experiments with thin disks of Steel; by Professor F. A. Abel, C.B., F.R.S.

Hardening &c. of Steel, Results of Experiments with reference to Occluded Gases; by Professor W. Chandler Roberts, F.R.S.

Further Experiments on Riveted Joints, Series IX.; by Professor Alex. B. W. Kennedy.

Experiments on Lap-Joints, with Rivets of different Sizes; by Mr. R. V. J. Knight.

The attendances at the Meetings have been generally satisfactory. There were at the Annual General Meeting 81 Members and 51 visitors; at the Spring Meeting 51 Members and 56 visitors; at the Summer Meeting 287 Members and 151 visitors; and at the Autumn Meeting 66 Members and 21 visitors.

The Summer Meeting at Newcastle was eminently successful, the numerous works ranged along the banks of the Tyne and Wear being thrown open with the utmost liberality to the inspection of the Members. To some of the principal of these works special excursions were organised by the exertions of the Local Committee; and on all of these occasions the Members were received and entertained with great hospitality.

In accordance with the Rules of the Institution, the President, two Vice Presidents, and five Members of Council in rotation, go out of office this day. The result of the ballot for the election of the Council for the present year will be reported to the Meeting.

APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.		£ s. d.
To Printing and Engraving Proceedings of 1881	920 8 5	
„ Reprinting former Proceedings	109 7 0	
	1029 15 5	
Less Authors' Copies of Papers, repaid	84 4 3	945 11 2
„ Printing Library Catalogue and Index of Papers		95 3 8
„ Stationery, Binding, and General Printing		197 11 10
„ Rent		550 0 0
„ Salaries and Wages		1203 9 0
„ Coals, Firewood, and Gas		30 1 8
„ Fittings and Repairs		64 17 9
„ Postages		236 5 10
„ Insurance		3 7 9
„ Travelling Expenses		10 17 11
„ Petty Expenses		54 6 6
„ Meeting Expenses—		
Printing	80 6 4	
Reporting	58 10 6	
Diagrams, Screen, &c.	13 9 0	
Travelling and Incidental Expenses	81 2 0	233 7 10
„ Research		136 11 2
„ Books purchased		11 16 7
Total Expenditure in 1881		3773 8 8
Balance, being excess of Receipts over Expenditure		474 15 11
		£4,248 4 7

Dr. BALANCE SHEET,

	£ s. d.
Capital of the Institution at this date	13,635 1 11
	£13,635 1 11

(*Signed*) EDWARD A. COWPER
THOMAS R. CRAMPTON } *Finance Committee.*

APPENDIX I.

FOR THE YEAR ENDING 31ST DECEMBER 1881. *Cr.*

Receipts.				£	s.	d.
By Entrance Fees—						
92 *New Members at £2*	184	0	0			
2 *New Associates at £2*	4	0	0			
13 *New Graduates at £1*	13	0	0			
2 *Graduates transferred to Members at £1*	2	0	0	203	0	0
„ Subscriptions for 1881—						
1050 *Members at £3*	3,150	0	0			
25 *Associates at £3*	75	0	0			
65 *Graduates at £2*	130	0	0			
2 *Graduates transferred to Members at £1*	2	0	0	3,357	0	0
„ Subscriptions in arrear—						
43 *Members at £3*	129	0	0			
2 *Associates at £3*	6	0	0			
2 *Graduates at £2*	4	0	0	139	0	0
„ Subscriptions in advance—						
18 *Members at £3*				54	0	0
„ Interest—						
From Investments	356	8	3			
From Bank	30	8	2	386	16	5
„ Reports of Proceedings—						
Extra Copies sold				108	8	2
				£4,248	4	7

AS AT 31ST DECEMBER 1881. *Cr.*

				£	s.	d.
By Cash—*In Bank*	471	16	1			
In Secretary's hands	250	0	0	721	16	1
„ Investments—						
£3,178 *London & N. W. Ry.* 4% *Debenture Stock*						
£2,200 *North Eastern* „ „ „ „						
£2,110 *Midland* „ „ „ „						
£1,800 *Great Western* „ „ „ „						
£9,288			*cost*	9,217	16	2
Note—The Market Value of these investments at 31st Dec. 1881 was £10,600						
„ Subscriptions in Arrear				318	0	0
„ Office Furniture and Fittings				350	0	0
„ Library and Proceedings				2,627	9	8
„ Drawings, Engravings, Models, Specimens, and Sculpture				400	0	0
				£13,635	1	11

Audited and Certified by

ROBERT A. McLEAN & Co., Chartered Accountants, 1 Queen Victoria St., E.C.

APPENDIX II.

LIST OF DONATIONS TO THE LIBRARY.

How to Manage a Steam Engine, by M. Powis Bale; from the author.

Application of Machine Power in Rock Drilling, by Richard Schram; from the author.

Catalogue of Mining Machinery, by Messrs. Oliver and Co.; from Mr. Richard Schram.

Abaissement des Hautes Eaux du Lac de Constance, by Arthur Achard; from the author.

The Worthington Steam Pumping Engine, by Henry R. Worthington; from Mr. Thomas Whiteside Rae.

Maps of the Irrawaddy Embankment Works; from Mr. Robert Gordon.

Institution of Civil Engineers, Presidential Address by James Abernethy, Esq.; from the author.

Adcock's Engineers' Pocket-Book for 1881; from the publisher.

Elements of Mechanism, by T. M. Goodeve; from the author.

Kaiser Ferdinands-Nordbahn, Oesterreich, Beschreibung der ausgestellten Objecte aus dem Maschinenwesen, Paris 1878; from Mr. Henry Chapman.

Kaiser Ferdinands-Nordbahn, Oesterreich, Abtheilung für Bau und Bahnerhaltung; from Mr. Henry Chapman.

Nouvel Indicateur Dynamométrique pour machines à vapeur, système Martin, by Paul Garnier; from Mr. Henry Chapman.

Deterioration of Boilers, Parliamentary Report; from the Admiralty.

Trial of Engine and Boilers at Messrs. Nuttall's, by Michael Longridge; from the author.

Civil Engineering, by Henry Law, George R. Burnell, and D. K. Clark; from Mr. D. K. Clark.

Fifty Years' Chart of the Iron Trade, by R. R. Mabson; from Mr. W. G. Fossick.

Society of Engineers, Presidential Address by Charles Horsley, Esq.; from the author.

House Drainage, Sewerage, and Ventilation, by Reginald E. Middleton; from the author.

List and Distribution Return of Establishment; from the India Office.

Catalogue of Machinery and Tools; from Messrs. Tangye Brothers.

Manchester Association of Foremen, Employers, and Draughtsmen; Report and Papers; from the Association.

Catalogue of Iron Wire, Wire-Rope, and Fencing; from Messrs. D. Rowell and Co.

Société des Ingénieurs Civils, Discours de M. Gottschalk, Président; from the author.

Kitchen and Hot-Water Boiler Explosions, by Samuel B. Goslin; from the author.

Board of Trade Experiments on Steel, by Thomas W. Traill; from the author.

The Steam Engine and its Inventors, by Robert L. Galloway; from the author.

Beretning om de for den norske industri vigtigste maskiner ved verdensudstillingen 1878 i Paris, by F. Størmer; from the author.

List of Chinese Lighthouses, Lightvessels, Buoys, and Beacons, 1881, by the Inspector General of Chinese Maritime Customs; from Mr. Robert Hart, Inspector General.

Brake Experiments on the Lancashire and Yorkshire Railway, by Capt. Douglas Galton, C.B., F.R.S.; from Mr. W. Barton Wright.

Instructions for the Working of Machinery, Army Circular 1879; from the War Office.

Instructions for the Storage and Inspection of Submarine, Mining, and Telegraphic Stores and Apparatus; from the War Office.

Gas and Electricity as Heating Agents, by C. William Siemens, F.R.S.; from the author.

Dynamo-Electric Current, and means to improve its Steadiness, by C. William Siemens, F.R.S.; from the author.

Notes on Northern Industries, by James S. Jeans; from the author.

Admiralty Tests of Mild Steel; from the Admiralty.

Revue industrielle, 1880; from Mr. Henry Chapman.

Reduction of the Postal Telegraph Tariff, by R. Price Williams; from the author.

Élévateurs et Plans Inclinés pour Canaux, by J. Hirsch; from the Public Works Department, France.

Steam Tramways, a pressing want of the times, by Henry Barcroft; from the author.

Navigation Improv'd, or the Art of Rowing Ships, by Thomas Savery, 1698, (reprint); from Mr. Richard B. Prosser.

Designs of Iron Buildings and Roofs; from Messrs. Frederick Braby and Co.

Catalogues of Zinc Roofing, and Photographs of Embossed Zinc Patterns; from Messrs. Frederick Braby and Co.

Mechanic's Magazine, vols. 1, 2, 3, 4, 28, 29; from Mr. Bryan Donkin, Jun.

Archæology of the West Cumberland Iron Trade, by H. A. Fletcher; from the author.

Dampfmaschinen und Transmissionen in den Vereinigten Staaten von Nord-Amerika, by J. F. Radinger; from the Austro-Hungarian Embassy.

Relative Corrosion of Iron and Steel, by William Parker; from the author.

Peculiarities of Behaviour of Steel Plates supplied for the Boilers of the Russian Yacht *Livadia*, by William Parker; from the author.

Chemins de fer à fortes Pentes, système Riggenbach, by Nicholas Riggenbach; from the author.

Mesure exacte des Hautes Pressions, et Frottement des Cuirs emboutis des presses hydrauliques, by Georges Marié; from the author.

Dock and Port Charges of the United Kingdom (supplement), by Robert Thubron; from the author.

Railway Rates on Iron and Iron-Making Materials; from the British Iron-Trade Association.

Report on Continuous Brakes, by F. J. Bramwell and E. A. Cowper; from the Midland Railway.

Dehnungszeichner, by Dr. W. Fränkel; from the author.

Explosion d'une Chaudière à vapeur dans les forges de Birchills Hall, Walsall, by M. Luuyt; from the author.

Explosion d'une Chaudière à vapeur dans la forge de Saint-Rollox, Glasgow, by M. Luuyt; from the author.

Portland Cement for Users, by Henry Faija; from the author.

Graphic Diagrams for Strength of Teak Beams, by Guilford L. Molesworth; from the author.

Festiniog Light Railway, by Guilford L. Molesworth; from the author.

Reports on Perkins Engines and Boilers; from the Perkins Engine Co.

Hydraulics and Hydraulic Motors, by Weisbach (translated by Du Bois); from Mr. Michael M. Brophy.

Instructions for Survey of Hull, Equipments, and Machinery, in Steam Ships carrying Passengers, by the Board of Trade; from Mr. Thomas W. Traill.

Principles of Mechanics, by T. M. Goodeve; from the author.

Patents for Inventions Bill, by the Society of Arts; from the Society.

Wind Pressure on Railway Structures, Report of Committee; from the Railway Department, Board of Trade.

Requirements for opening New Railways; from the Railway Department, Board of Trade.

British and Foreign Trade Marks, by G. G. M. Hardingham; from the author.

Metallurgy: Fuel, Fireclays, Copper, Zinc, Brass, &c., by John Percy; from Mr. T. Budworth Sharp.

Extracts from papers on Screw Threads and on Decimal Measure of Length, by Sir Joseph Whitworth; from the author.

Résistance des Matériaux, by A. Madamet; from the author.

Locomotiv-Versuchsstationen, by Alexander Borodine; from the author.

River Tyne Improvement, longitudinal section from the sea to Wylam, by P. J. Messent; from the author.

Repairs and Renewals of Locomotives, by Alexander McDonnell; from the author.

Herreshoff Boiler, and system of Machinery, Report by U. S. Naval Engineers, 1880; from Mr. J. A. Tobin.

Herreshoff Steam Yacht *Leila*, Report by U. S. Naval Engineers, 1881; from Mr. J. A. Tobin.

Calendar of King's College, London; from the College.

Applications of Electric Energy to Horticulture and Agriculture; and Secondary Batteries; by C. William Siemens, F.R.S.; from the author.

L'Électricité et ses applications, Paris 1881; from Mr. Arthur Barclay.

Veränderung der Elasticitätsgrenze und des Elasticitätsmoduls verschiedener Metalle, by Professor Bauschinger; from the author.

Catalogue of Iron Buildings; from Mr. John Lysaght.

Les Progrès futurs de la Locomotive au point de vue de l'Économie de Combustible, by Georges Marié; from the author.

Engravings of Russian Railway Rolling Stock; from Mr. Thomas Urquhart.

Die Müller'schen Schieberdiagramme in Anwendung auf die Steuerungen der Betriebsdampfmaschinen, by Alfred Seeman; from Mr. Thomas Urquhart.

Die Umsteuerungen der Locomotiven in rein graphischer Behandlungsweise, by Albert Fliegner; from Mr. Thomas Urquhart.

Die Wiener Stadtbahn oder Gürtelbahn; from Mr. Joseph Fogerty.

Port de Rouen, Rapport sur les Améliorations dont sont encore susceptibles la Seine Maritime et son Estuaire, by L. L. Vauthier; from the author.

Laying of the first Submarine Telegraph Cable between Dover and Calais in 1851; from Mr. Thomas R. Crampton.

Strata of Northumberland and Durham, as proved by Borings and Sinkings; from the North of England Institute of Mining and Mechanical Engineers.

Electricity and Magnetism, works exhibited at Paris 1881, by Latimer Clark; from the author.

Transatlantic Lines and Steamships, by Arthur J. Maginnis; from the author.

Roorkee Hydraulic Experiments, 3 vols., by Capt. Allan Cunningham, R.E.; from the author.

Birmingham Inventors and Inventions, by Richard B. Prosser; from the author.

Electricity and Magnetism, by Fleeming Jenkin, F.R.S.; from the author.

Science and Industry, Presidential Address to the Birmingham and Midland Institute, by C. William Siemens, Esq., F.R.S.; from the author.

Catalogue of Engineering Work; from Messrs. Buckley and Taylor.

Exact numerical Quadrature of the Circle &c., by James Steel; from the author.

Charts and Plans for communication between Ireland and West of Scotland, 1809, by Thomas Telford; from Mr. William Anderson.

Photograph of Water Tower at Ramsgate Water Works; from Mr. William A. Valon.

Étude sur le Rivetage, by Baron G. Clauzel; from M. M. Berrier-Fontaine.

Cooking and Heating by Gas, by William Denny, F.R.S.E.; from the author.

Attachments to Locomotive Boilers, by Matthias N. Forney; from the author.

Photographs of Compound Pumping Engines of Kimberley Water Works; from Messrs. Simpson and Co.

Economical use of Gas Engines for the production of Electricity, by W. E. Ayrton, F.R.S.; from Mr. Arthur Barclay.

The Edystone Lighthouse, by John Smeaton; from Mr. Alan C. Bagot.

Machine Lange pour le Peignage des Laines; from the President.

Mémoire sur le mouvement complet du navire oscillant sur eau calme, relation des expériences faites sur *l'Elorn*, (Mémorial du Génie Maritime, 10th part, 1874), by O. Duhil de Bénazé and P. Risbec; from M. M. Berrier-Fontaine.

Russian Railways, report of third annual conference of Locomotive Superintendents; from Mr. Thomas Urquhart.

Running Rules, Grazi and Tsaritsin Railway, Russia, by Thomas Urquhart; from the author.

Reports of the Academy of Sciences, France; from the Academy.

Reports of the Royal Academy of Sciences, Belgium; from the Academy.

Reports of the Royal Institute of Engineers, Holland; from the Institute.

École des Ponts et Chaussées, Paris, Engravings and Library Catalogue; from the École.

Annales des Ponts et Chaussées, Paris; from the Directors.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Report of the French Association for the Advancement of Science; from the Association.

Journal of the Marseilles Scientific and Industrial Society; from the Society.

Proceedings of the Engineers' and Architects' Society of Milan; from the Society.

Proceedings of the Engineers' and Architects' Society of Rome; from the Society.

Proceedings of the Engineers' and Architects' Society of Florence; from the Society.

Proceedings of the Engineers' and Architects' Society of Canton Vaud; from the Society.

Proceedings of the Engineers' and Architects' Society of Austria; from the Society.

Proceedings of the Architects' and Engineers' Society of Hanover; from the Society.

Proceedings of the Engineers' and Architects' Society of Prague; from the Society.

Proceedings of the Industrial Society of St. Quentin; from the Society.

Proceedings of the Industrial Society of Mulhouse; from the Society.

Proceedings of the Industrial Society of the North of France; from the Society.

Proceedings of the Saxon Society of Engineers and Architects; from the Society.

Proceedings of the Swedish Society of Engineers; from the Society.
Journal of the Norwegian Polytechnic Society; from the Society.
Journal of the Franklin Institute; from the Institute.
Transactions of the American Society of Civil Engineers; from the Society.
Transactions of the American Institute of Mining Engineers; from the Institute.
Report of the Smithsonian Institution; from the Institution.
Proceedings of the United States Naval Institute; from the Institute.
Proceedings of the American Meteorological Society; from the Society.
United States Patent Office Gazette; from the Office.
Professional Papers on Indian Engineering; from the Thomason College.
Proceedings and Journal of the Asiatic Society of Bengal; from the Society.
Report of the Sassoon Mechanics' Institute, Bombay; from the Institute.
Proceedings of the Institution of Civil Engineers; from the Institution.
Journal of the Iron and Steel Institute; from the Institute.
Transactions of the Society of Engineers; from the Society.
Journal of the Society of Telegraph Engineers; from the Society.
Transactions of the Institution of Civil Engineers of Ireland; from the Institution.
Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.
Proceedings of the South Wales Institute of Engineers; from the Institute.
Transactions of the Institution of Engineers and Shipbuilders in Scotland; from the Institution.
Proceedings of the Chesterfield and Derbyshire Institute of Mining, Civil, and Mechanical Engineers; from the Institute.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers; from the Institute.
Proceedings of the Cleveland Institution of Engineers; from the Institution.
Transactions of the West of Scotland Mining Institute; from the Institute.
Proceedings of the Royal Society of London; from the Society.
Proceedings of the Royal Society of Edinburgh; from the Society.
Proceedings of the Royal Institution; from the Institution.
Transactions of the Institution of Surveyors; from the Institution.
Proceedings of the Association of Municipal and Sanitary Engineers and Surveyors; from the Association.
Journal of the Royal United Service Institution; from the Institution.
Papers of the Royal Engineer Institute; from the Institute.
Proceedings of the Royal Artillery Institution; from the Institution.
Journal of the Royal Agricultural Society of England; from the Society.
Journal of the Statistical Society; from the Society.
Report of the British Association for the Advancement of Science; from the Association.

Report of the Royal Cornwall Polytechnic Society; from the Society.
Report of the Miners' Association of Cornwall and Devon; from the Association.
Transactions of the Institution of Naval Architects; from the Institution.
Transactions of the Royal Institute of British Architects; from the Institute.
Report of the British Association of Gas Managers; from the Association.
Proceedings of the Physical Society of London; from the Society.
Proceedings of the Literary and Philosophical Society of Manchester; from the Society.
Report of the Manchester Geological Society; from the Society.
Journal of the Royal Scottish Society of Arts; from the Society.
Proceedings of the Philosophical Society of Glasgow; from the Society.
Transactions and Proceedings of the Royal Irish Academy; from the Academy.
Transactions of the Liverpool Engineering Society; from the Society.
Journal of the Liverpool Polytechnic Society; from the Society.
Proceedings of the Birmingham Philosophical Society; from the Society.
Journal of the Society of Arts; from the Society.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Report of the Boiler Insurance and Steam Power Company; from Mr. Niel McDougall.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Insurance Company; from Mr. Michael Longridge.
Catalogue of the Liverpool Free Public Library; from the Committee.

The Engineer; from the Editor.
Engineering; from the Editor.
Iron; from the Editor.
The Mining Journal; from the Editor.
The Railway Record; from the Editor.
The Colliery Guardian; from the Editor.
The Iron and Coal Trades Review; from the Editor.
Ryland's Iron Trade Circular; from the Editor.
Revue générale des Chemins de fer; from the Directors.
Der Civilingenieur; from the Editor.
The Railroad Gazette; from the Editor.
The Railway Engineer; from the Editor.
The Engineering and Mining Journal; from the Editor.
The Telegraphic Journal and Electrical Review; from the Editor.
The Fireman; from the Editor.
The Marine Engineer; from the Editor.
The Contract Journal; from the Editor.

The President thought the Institution had cause in several respects to congratulate itself upon having been at work in a thoroughly useful manner. The result of the operations of the Riveting Committee, showing that instead of 55 per cent. they had got up to 63·7 per cent. of the full strength of the plate in single-riveted lap-joints in $\frac{3}{8}$-in. steel plates, was in itself eminently satisfactory; and the other result of 53 against 46·8 for $\frac{3}{4}$-in. plates was another gain in the same direction. These were practical results which would be useful to every boiler-maker and engineer who chose to use steel, and to pay any attention to the experiments of the Committee. The report also touched upon the fact that their numbers were largely increasing, and that they were now in possession of a capital of £13,600, which in itself was gratifying, as showing the progress and stability of the Institution. He did not know that there were any other particular points which he need touch upon, except that they ought to express their gratitude to Professor Abel, Professor Kennedy, and other gentlemen who had assisted the Research Committees in various ways; there was still a great deal to be done, and he hoped they would be able to accomplish much more this year. With regard to the Newcastle meeting, they had reason both to congratulate themselves, and to thank their Newcastle friends very heartily for having taken the trouble to organise, in such a thorough and business-like manner, the visits and operations which had been carried out at Newcastle. They had learnt and seen a great deal there, and he was perfectly assured that the members had received a great deal of pleasure from their visit, and from the extremely kind manner in which they had been received.

He begged to propose that the Report of the Council be adopted, and printed in the usual manner.

The motion was carried unanimously.

The PRESIDENT announced that the Ballot Lists for the election of Officers had been opened by a committee of the Council, and the following Members of Council were found to be elected for the present year:—

PRESIDENT.

PERCY G. B. WESTMACOTT, ...	Newcastle-on-Tyne.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, F.R.S., ...	Northallerton.
GEORGE B. RENNIE, ...	London.
CHARLES P. STEWART, ...	Sunninghill.

MEMBERS OF COUNCIL.

WILLIAM ANDERSON, ...	London.
THOMAS R. CRAMPTON, ...	London.
FRANCIS C. MARSHALL, ...	Newcastle-on-Tyne.
JOHN PENN, ...	London.
E. WINDSOR RICHARDS, ...	Middlesbrough.
WILLIAM RICHARDSON, ...	Oldham.

The Council for the present year would therefore be as follows:—

PRESIDENT.

PERCY G. B. WESTMACOTT, ...	Newcastle-on-Tyne.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., ...	Newcastle-on-Tyne.
SIR FREDERICK J. BRAMWELL, F.R.S., .	London.
EDWARD A. COWPER, ...	London.
THOMAS HAWKSLEY, F.R.S., ...	London.
JAMES KENNEDY, ...	Liverpool.
JOHN RAMSBOTTOM, ...	Alderley Edge.
JOHN ROBINSON, ...	Manchester.
C. WILLIAM SIEMENS, D.C.L., LL.D., F.R.S., ...	London.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., ...	Manchester.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, F.R.S., ...	Northallerton.
CHARLES COCHRANE, ...	Stourbridge.
JEREMIAH HEAD, ...	Middlesbrough.
GEORGE B. RENNIE, ...	London.
CHARLES P. STEWART, ...	Sunninghill.
FRANCIS W. WEBB, ...	Crewe.

MEMBERS OF COUNCIL.

DANIEL ADAMSON, ...	Manchester.
WILLIAM ANDERSON, ...	London.
THOMAS R. CRAMPTON, ...	London.
DAVID GREIG,.	Leeds.
J. HAWTHORN KITSON, ...	Leeds.
FRANCIS C. MARSHALL, ...	Newcastle-on-Tyne.
WILLIAM MENELAUS, ...	Dowlais.
ARTHUR PAGET, ...	Loughborough.
RICHARD PEACOCK, ...	Manchester.
JOHN PENN, ...	London.
SIR JAMES RAMSDEN, ...	Barrow-in-Furness.
E. WINDSOR RICHARDS, ...	Middlesbrough.
WILLIAM RICHARDSON, ...	Oldham.
JOSEPH TOMLINSON, JUN., ...	London.
R. PRICE WILLIAMS, ...	London.

The PRESIDENT said that, on rising from the chair for the last time, he had but a very few words to say, but they were all in thanks to the Members for their kindness and consideration towards him during the time he had held that position; and whatever his shortcomings might have been, he could only say that he had attempted, at all times, to do the best he could for the interests of the Institution and its Members, and he trusted it had not suffered in any respect during his tenure of office. He believed every member and officer of the Institution had done his best in its interests; and

the Report, which they had just heard read, had told of the progress that had been made during the last year, both in the number of members added to the ranks (in which number were included some very distinguished men), and also in the interesting character of the papers, and in the results that had been obtained by the patient and persevering exertions of the Research Committees—results which he trusted would prove of considerable value to many members. He had but two words more—one was to say that, having worked, and (he thought he might say without vanity) having worked hard, for the Institution during more than thirty years, he was far more than repaid if he had met with the approbation of the Members. The other was that he vacated the chair with the satisfaction of knowing that it would be filled, far better than he had ever filled it, by the new President, who was known to so many as an excellent mechanical engineer, and one thoroughly fitted to fill the important post of President of the Institution.

The chair was then taken by Mr. Percy G. B. Westmacott, President elect.

Mr. WESTMACOTT said the members had conferred a great honour upon him, and placed an important trust in his hands—the greatest honour, he believed, as it was the highest trust, which the Institution could bestow upon any one of its members. He thanked them sincerely for the honour they had done him, and he should respect and cherish that trust. He confessed that he had had serious misgivings as to his own fitness for such an important post; but when he reflected that even the most talented, the most able, accomplished, and experienced member would fail to preside over the Institution with any degree of success, unless he could command the support and good will of the members, he took courage from the kind reception he had met with, and from the many friendly assurances of support he had received. He felt sure that they would give him every assistance, and would not withhold their forbearance. He was, as they knew, no speaker, but he trusted he might be found not altogether deficient in the more essential duties of the office

which lay before him. At any rate he could assure them that he was sensible of the responsibilities which now devolved upon him, and should do all in his power to further the interests and prosperity of the Institution—a prosperity which he was glad to find was advancing steadily year by year. He should do all he could to uphold and sustain the dignity of the chair, which had been raised to its high position by the eminent men who had previously occupied it.

Mr. JEREMIAH HEAD said, before they proceeded any further with their business, he must ask the meeting to perform a necessary, and yet he was sure a very pleasant duty. He begged leave to move, "That the best thanks of this Institution be given to the retiring President, Mr. E. A. Cowper, for his conduct in the chair during the last two years." He assured them that when, more than two years ago, the office of President was about to become vacant, the Council considered with no little anxiety whom they could best select to occupy that important position. They did not forget the long list of eminent men who had filled it during more than thirty years, beginning with George Stephenson and ending with John Robinson; and, with the sense of responsibility full upon them, they turned to Mr. Cowper, one of the few remaining founders of the Institution who was still able to take an active part in its direction. They were not unmindful of the many ways in which Mr. Cowper had helped forward mechanical science through that long period: they were not unmindful of his high qualities for such a position as that of President, and for guiding and assisting the members in their discussions and debates. They therefore asked him if he would be kind enough to accept their nomination to the office. If he remembered rightly, when Mr. Cowper did accept that nomination, which was afterwards unanimously confirmed by the members, he spoke of himself as doubtful whether his powers would be equal to the occasion; but at the same time he assured them that his object and aim would be to leave the Institution in at least as successful a position as he found it. Now they knew from the report which had just been read, and from the report read last year, that the Institution had continued to advance in every respect. They were now stronger

in their membership list by something like one hundred names than they were when Mr. Cowper took office; and their funds (although perhaps that was the least important part of their success) were larger by £1,300 than they were at that time. Considering also the number and character of the meetings that had been held, the large amount of work that had been done, and the fact that the scientific research committees, if not absolutely originated and organised, had really got into efficient working order during Mr. Cowper's reign, and had thereby inaugurated, as it were, a new era of activity and usefulness for the Institution—considering all this, he thought that they would agree with him that Mr. Cowper had fully and fairly redeemed his promise. Under these circumstances he asked them cordially to pass the vote of thanks to Mr. Cowper which he had now the honour to propose. He believed that the vote would be seconded by his friend, Mr. Crampton, who was also one of the oldest members of the Institution, having joined in the year 1847.

Mr. T. R. Crampton said that not only on this occasion, but in fact on all occasions, he grieved that he had not the power of language to express all he felt. He had known Mr. Cowper for some forty years, and had been intimately connected with him, and had a great deal to do with him for the whole of that period; and he could only say that the still more intimate connection he had had with Mr. Cowper during the last two years on the Council of the Institution, and his knowledge of the way in which its affairs had been conducted, made him proud to feel that he had been his personal friend so long. Few of the members could imagine the difficulties that the President of the Institution had to encounter and overcome, or the time that was required to be given to its general interests. In fact not many were aware of the time that Mr. Cowper had given to their welfare, and of the ability he had exercised in doing all that had to be done. As one of the oldest members of the Institution, he most heartily seconded the motion, and felt certain that the vote would be unanimous in its favour.

The resolution was carried by acclamation.

Mr. COWPER said he hardly knew how to express himself as he ought to do, in thanking the members on this occasion. He might say that it was the proudest moment of his life. He never expected to have the happiness of filling the chair so much to their satisfaction as it appeared he had succeeded in doing. He had striven to fill it to his own satisfaction, and to work in an honest and straightforward way; and if what he had done had met with their approbation, he was far more than repaid.

The PRESIDENT asked whether any gentleman present had any observations to make upon the reports on the Hardening &c. of Steel, and on Riveted Joints, published in the last number of the Institution Proceedings.

Mr. ANDERSON said, as Chairman of the Committee of Research on the Hardening and Tempering of Steel, he had, in the first place, to express his regret that, owing to prolonged absence from England and extreme pressure of business, he had not been able to pay the attention to the subject which he had hoped to be able to give it. He wished however to point out to the members that his friend, Professor Chandler Roberts, had completely upset a theory which was advanced in the First Report as to one of the probable causes of the hardening of steel. This theory (Proceedings 1881, p. 692) was that the power possessed by steel and other metals of occluding or taking into themselves volumes of gases sometimes very large as compared with their own volumes, thereby separating to some extent the particles of their own substance, might cause softness in those metals; and the fact that these same gases were driven out by heating, and that, if the substance was suddenly cooled, the particles would shrink together before the gases could be reabsorbed, might possibly account for the hardening. Professor Chandler Roberts however (Proceedings 1881, p. 706) had completely upset this view in a most remarkable experiment, which he (Mr. Anderson) had been fortunate enough to see performed at the Royal Mint. In that experiment steel was hardened in what might be called an absolute vacuum,

which was produced by means of the Sprengel air-pump. Pieces of steel were exposed for a long time in vacuo to a high temperature, so as to make sure that whatever gases might have been occluded in them were expelled. The steel was afterwards hardened and tempered in the vacuum, thereby proving that the driving out of the occluded gases could not possibly have anything to do with the phenomenon. He thought that was a great step in advance, for it had disposed, at any rate, of one possible theory on the subject. What was still more remarkable was that Professor Chandler Roberts, with that extended knowledge which he possessed on these subjects, had discovered that Réaumur in the last century had come to the same conclusion, by means of an experiment conducted with an apparatus much less perfect than that which Professor Chandler Roberts had used. We were as much as ever in the dark as to the actual causes of the hardening of steel, but the researches of Professor Abel (Proceedings 1881, p. 696) appeared to be extremely promising; and he hoped it would be reserved for the Institution, at some not very distant date, to be the means of solving the difficulties which now surrounded the subject.

Mr. E. A. Cowper thought they might congratulate themselves that the researches of Professor Abel had made a decided step further in advance; because his late experiments, showing how far the carbon was combined with iron in different conditions, foreshadowed the discovery of the real difference between hard and soft steel. That report was already in their hands; and if any gentleman had any facts that would throw further light upon the difference between hard and soft steel, the Committee would be very glad to receive the communication; and if it was written, all the better, as it would probably be more exact.

Professor A. B. W. Kennedy said he had read Mr. Anderson's report, and the other reports on the question of steel, with the greatest interest, and should like much to take part in a discussion on the subject. He did not know if he was wrong in suggesting that, as this matter had not been mentioned in the notice paper, it should be

brought up again at their next meeting, when there would have been ample time for preparation, and when he believed they would have a very important discussion.

The PRESIDENT said he hoped there would be another report in the hands of the members before the next meeting, and it would then be competent to discuss the subject.

The following paper was then read and discussed :—

On Meters for registering Small Flows of Water; by Mr. J. J. Tylor, of London.

At 10 P.M. the Meeting was adjourned till the following evening.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, 27th January, 1882, at Half-past Seven o'clock p.m.; PERCY G. B. WESTMACOTT, Esq., President, in the chair.

The discussion on Mr. Tylor's paper was resumed and concluded.

The PRESIDENT proposed a vote of thanks to Mr. Tylor for his paper, which was passed.

The following paper was read and discussed : —

On the Bazin system of Dredging ; by Mr. Alfred A. Langley, of London.

On the motion of the President, a vote of thanks was passed to Mr. Langley for his paper.

The following paper was read, and the discussion adjourned to the next Meeting :—

On Hydraulic Lifts for Passengers and Goods; by Mr. Edward Bayzand Ellington, of London.

On the motion of the President, a vote of thanks was passed to Mr. Ellington for his paper.

The PRESIDENT moved a vote of thanks to the Institution of Civil Engineers, for their kindness, so often repeated, in granting their rooms for the use of the Institution. The vote was carried by acclamation.

The Meeting then terminated.

ON METERS FOR REGISTERING SMALL FLOWS OF WATER.

By Mr. J. J. TYLOR, of London.

The writer proposes to commence by a short account of the chief Water Meters which have been used in this country, mainly indeed for purposes of trade supply, but also occasionally for domestic supply; and also of some which are used on the Continent for domestic as well as trade supply, and which can be made available for England. In each case his special object will be to show how far the design is effective in the measurement of *small* flows.

Parkinson's Meter.—This is in fact an adaptation of the gas-meter, invented by Mr. Parkinson, to the measurement of water. It was described in a paper read before the Institution in 1851 (Proc. Jan. 1851, p. 19), and is shown in Figs. 1 and 2, Plate 1. A trough A, in which the height of the water-level is maintained constant by means of a ball-valve, passes the water entering it from the main through an overflow pipe into a horizontal rotating drum B, divided into segmental compartments. The water enters a compartment situated on one side of the horizontal axis of the drum; and thus, the weight on one side being increased, the drum revolves, the full compartment sinks, and the water escapes into the case supporting the drum, and thence to the exit pipe. As the first compartment recedes, another compartment takes its place, and is filled and emptied in its turn. The revolutions of the measuring drum are recorded by a train of wheels indicating on a dial; and, the contents of the compartments being known, the measure is at once given.

The character of this meter, which is largely in use, necessitates its being placed on the highest point of the house service. This is an objection, both on account of the exposure to frost and of the inconvenience to the consumer in the inspector having to pass

through the house up to the highest rooms in order to examine the meter. The meters are however very reliable, and are capable of registering a very small flow of water with exactness.

Kennedy's Meter. — This meter (already described in the Proceedings, 1856, p. 156) is shown in Fig. 3, Plate 1. It consists of a cylinder, in which a piston, packed with a rolling ring of india-rubber, works upwards and downwards. Each stroke of the piston is recorded on an index by means of a rack A on the piston-rod, driving a pinion B, from one side of which project a pair of arms that act alternately to lift a tumbler C. This tumbler, by falling over its centre of motion, reverses a four-way cock D, serving as a supply and discharge valve. These meters are extremely reliable for any quantities passed by the meter, as long as the packing of the cylinder remains quite sound, and as long as the ground-in four-way cock does not leak or jam fast. Irregularity in the section of the india-rubber ring sometimes causes the piston to jam or become tilted, so that the water may pass without registration. In one of the author's experiments, a meter of this type, fresh from the maker's hands, permitted water at the rate of the full bore of a $\frac{1}{2}$-in. pipe to pass without registration, owing to the fact that the piston was somehow forced by the water past the limit of its stroke, and thus got out of gear. These meters are somewhat noisy in action; and the reversal of the current at each stroke causes, at the higher pressures, considerable shocks in the mains. During the reversal of the valve water passes without registration, though for a very short space of time; and, if the reversing cock is stiff, the meter may possibly stop at this point.

Frost's Meter.—This meter (described in Proceedings 1857, p. 172) consists of a piston working in a cylinder, as shown in Fig. 4, Plate 1. The reciprocating motion of the piston is caused by a double set of slide-valves, with ports similar to those of the steam-engine. A three-port valve A, worked by tappets on the piston-rod B, gives motion to an auxiliary piston C, set at right angles to the main cylinder, and working the main induction and exhaust

valve D, which is also a three-ported slide-valve. The meter cylinder is lined with brass, and the piston is packed with double cup-leathers. These are liable to stick and get corroded if left standing, and they also wear faster than the rolling ring of the Kennedy meter. The flat three-port valves are also liable to wear round, and the mechanism is more complicated than Kennedy's. The meters however weigh much less and are quieter in action, registering with great accuracy at high and low velocities, as long as they are in good order.

Extreme cold is a dangerous enemy to all classes of piston meters, because, owing to their size, they cannot be cheaply protected from changes of temperature; and the expense of repair is great in such cases, because the cylinder is usually the part which gives way. The water-power consumed in working these meters is considerable at quick speeds, as a heavy, tight-fitting piston has to be moved; and, in case no water passes through the meter for several weeks, the piston is apt to stick. These meters are also noisy in action, and the flow is somewhat intermittent. In this respect they are not so well adapted for small flows, or for domestic purposes, as inferential meters are.

Siemens' Turbine Meter.—This was brought out in two forms, one (described before the Institution, Proceedings 1854, p. 12, and 1856, p. 113) consisting of a reaction turbine or vertical Barker's mill; and the other of a fan, driven by water impinging on the blades at the circumference and finding its way out towards the centre. The latter form was first tried in practice; and the writer has lately seen some of these meters, which, though useless for measuring small flows of water, seemed to be reliable for large flows.

Messrs. Guest and Chrimes, the makers of these water-meters, appear to have definitely adopted the reaction turbine; in which form this water-meter has come into very extended use, both in England and abroad. The modified construction of this meter, as shown in Fig. 5, Plate 2, includes a reaction turbine A, rotating on a steel-shod pivot B, provided with means of lubrication. The water enters at the upper part of the wheel or drum, which at the point of entrance C has its neck contracted so as to form a more or less water-

tight joint with the stationary inlet spout D, which conducts the water to the wheel. The water passes outwards through spiral grooves or channels formed within the drum, and makes its exit into the case or meter box through contracted tangential openings. The reaction of the water against the grooves in the drum, as well as against the more quiescent fluid in the case, causes the drum to revolve. Vanes E, or drag-boards as Dr. Siemens calls them, projecting from the revolving drum, prevent its increase in velocity from being more than is proportionate to the increase in the velocity of the water; thus practically ensuring that the number of revolutions per unit of water will remain constant, at whatever speed the water may pass.

It is evident that the neck C, forming a joint between the revolving drum and the stationary inlet spout D, is the weak point of this meter, since any leakage at this point allows water to escape without measurement. The bearing at this neck cannot be made long or very close-fitting, as the friction of the drum is a very important element, when small flows have to be measured. Again the neck, being of considerable diameter, is liable to corrode and set fast, in case the meter remains long at a standstill.

One great advantage of this water-meter is that the correct action of the drum does not depend on its exact fit into the outer case; so that considerable wear of the toe-piece, or vibration through the wear of the bearing, does not much affect the registration, or stop the drum by causing contact with the case.

Siemens' Fan Meter.—This differs from the last in the substitution of a wheel with blades for the reaction turbine, as shown in Fig. 6, Plate 2. This wheel or fan A is driven by the impact of the water entering through oblique circular apertures B in the casing C, and the water, after setting the fan in motion, passes upwards towards the exit. The fan's velocity of rotation is checked by projecting plates, equivalent to the vanes or drag-boards of the last meter, but placed in the upper part of the case. The regulation of the meter is effected by alterations in the size of these projecting plates.

This meter, which is largely used on the Continent though but

little known in England, has proved successful when carefully made. The higher position of the outlet however diminishes the efficiency with small flows, as the water, if not projected with considerable velocity, tends to take the direct path from inlet to outlet without impinging on the blades of the fan. The wearing away of the toe-piece also causes the fan at length to come in contact with the case; and the fit of the fan in the case determines the accuracy of the registration. Further, the position of the case, below the level of the outlet, renders the meter liable to be choked by sediment; and, the case being of iron, a great quantity of rust finds its way into the moving parts, and is apt to set the fan fast in case of temporary disuse.

For small flows this meter has an advantage over the other design, because in the absence of the turbine neck, with its risk of leakage, all water has to pass the blades of the fan, and so produces an effect on the registration as long as the quantity passing is sufficient to move the fan at all.

Tylor's Meter.—This meter like the last consists of a fan revolving in a case, Figs. 7 and 8, Plate 3, but both fan and case differ in important points from those of Dr. Siemens. Water, entering by oblique rectangular vertical openings A, sets the fan B in motion, and escapes at other openings C on the same level, the inlets and outlets being so situated that two or more blades of the fan are always in the direct path of the water in its natural passage through the meter.

The fan itself consists of a solid wheel made in one piece from a preparation of india-rubber, very strong, and of almost the same specific gravity as water. In some cases, especially for the larger sizes of meter, the fans are made of brass. In that case the shoulder, where the blade joins the boss, is placed at an angle to the axis of the spindle, so as to tend to lift the fan at the higher velocities, and thus avoid wear of the toe-piece. The same result is obtained in the india-rubber fan by its low specific gravity.

The toe-pieces for all sizes of meter are made of a special preparation of bronze, to avoid the destruction by rust to which the toe-pieces of other rotary meters, having steel points, are liable.

The case is of brass, and is formed of two half ellipses, Fig. 8, so placed together that at their junction a projection D is left at each side. The fan only approaches the case at four points, namely between each outlet C and the nearest inlet A, and at these projections. The object of this peculiar form is to prevent the choking of the meter by sediment or rust, and also to prevent the fan from continuing to turn after the source of supply is shut off. This obviates the common difficulty in rotary meters, namely that the moving part of the meter continues to rotate for many revolutions after the water has ceased to pass. This motion is partly caused by the *vis viva* of the fan, and partly by a current of water continuing to revolve in the lower part of the meter case, and carrying the fan round with it, after flow through the meter has ceased. In the present meter the projections D D in the case regulate the movement of the fan at the greater velocities, so that a unit of water moving at a high velocity is prevented from causing more revolutions of the fan than a unit of water at lower velocity; while the centrifugal force of the water produces a back current from the projections, and breaks up any tendency the water may have to continue rotating after the flow through the meter has ceased.

Another improvement in this meter is an appliance for regulating the speed of the fan by a counter current of water, admitted through a small hole at E, Fig. 8, and so arranged that it is adjustable from the outside of the case. This is of great convenience in testing, and also for persons making use of these meters, since any error in registration, springing from long use or accident, can be remedied without taking the meter to pieces or sending it back to the manufacturer.

The defect of this meter is that, like all rotary meters, it is liable to pass a certain quantity of water without registration. This quantity can be limited to an amount comparable with the minimum registration of piston meters; but at the expense of rendering the meter too delicate for use in corrosive water. Some 15,000 of these meters are in use for domestic supply, in Europe and the colonies.

In concluding this part of the paper the author wishes to draw attention to the great influence of Dr. Siemens' invention on the

introduction of rotary meters, and to the fact that to his original designs all the rotary meters which have come into use owe their principles of construction.

Measurement of Small Flows.—In practice abroad, where, for domestic supply, rotary meters are chiefly employed, a meter having moderate accuracy with very small flows is found the most advantageous. Cisterns are not in use, and the consumer cannot therefore conveniently defraud the company by allowing the water to trickle so slowly as to escape registration. As a matter of fact, it is certain that in ordinary use the quantity of water drawn at very slow speeds, in domestic supplies, is very small. Accordingly in Russia, Germany, Austria, Italy, and France, the rotary meters described in this paper are used almost exclusively for domestic supply, and the payments for water are collected according to the registration of the meters.

In England detailed experiments have always been made in practice, as far as the author is aware, with quantities sufficient for trade supplies, and therefore run at considerable speeds.

If however meters are to be employed for domestic service, it will be necessary to register small quantities, at least in cases where cisterns are used, and the question arises how far the existing meters are capable of performing this function. Now the experience of the Continent proves that there is no difficulty in registering small quantities, whether with a rotary or piston meter, provided they are not drawn at a very slow speed. If the speed be very slow, then a rotary meter at any rate becomes less reliable, as shown by Tables I. and II., which give several tests of rotary meters. Assuming that this is not the case with the piston meter, we may fix a rotary and a piston meter together on the main of a dwelling house, and then see whether there is any marked difference between the registration of the two, indicating that a portion of the water has been drawn very slowly. Three experiments of this kind are given in Tables III.–V. annexed, for houses of different classes; and it will be seen that, while the difference is usually small, the rotary meter shows the *greater* flow, proving that in practice no error arises from this cause. In these

cases both meters were tested with measured quantities, both before and after the experiments, in order to make sure that they were in good order. Table VI. gives a similar trial carried out at Edinburgh, and here the rotary meter shows a distinct deficiency; but the variations between the two piston meters are also noticeable.

District Meters.—To provide against loss of water by waste from the mains, or in supplies not controlled by a water meter, the system introduced by Mr. Deacon* at Liverpool, and carried out by Mr. Muir of the New River Water Company, Mr. John Taylor of the Lambeth Water Company, and other engineers, will prove of service.

The town to be examined is first divided into convenient districts of from 500 to 5000 persons, in such a way that each district is supplied from one main. On this main a registering meter is placed, and the consumption by day and night ascertained. If the amount of flow between midnight and five o'clock in the morning is excessive, the sluice valves controlling each street are successively shut off at intervals of ten to fifteen minutes, the time of each shut-off being noted. The diagram of the meter will allow the flow into each street from the trunk main to be ascertained, and also that in the trunk main by itself.

To ascertain whether waste occurs in the main, or outside the houses, external stop-cocks are necessary. These stop-cocks having all been shut in any particular street, the diagram will show whether waste occurs, since any water passing can only do so by leakage from the main or from the services between the stop-cock and the main.

The individual houses where waste is occurring may be detected by listening for the flow of water at night time, if external stop-cocks or other means of access to the services are provided. Such houses having been noted, notices to put the fittings in order are served on the occupiers. If external stop-cocks are not provided, house-to-house inspection in the streets found to be wasteful will detect any waste from defective fittings.

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* This system, and the meter invented by Mr. Deacon, are fully described in Proc. Inst. C.E., vol. xlii., p. 143.

The following is a description of a recording apparatus applicable to this system, which has been applied by the author to the Tylor meter. Above the meter, the movements of which are to be recorded, and fixed to its upper flange, is placed clockwork, so constructed as to move a strip of paper, about one inch broad, longitudinally, and with an intermittent but regular movement, under a pencil or pen free to move transversely. This pencil or pen is connected by a cam and train of wheels with the registering pinion of the water meter, in such a manner that the movement of the pencil the whole way across the strip of paper corresponds to either 500 or 1000 gallons registered by the water meter. The completion of the movement of the pencil across the paper (Fig. 9, Plate 4) is marked by its sudden return to the side of the strip whence it started, and the interval between two successive transverse marks thus made corresponds to the time occupied in the passage of the above quantity of water. The time is also marked every hour independently by a pricker connected with the clock, as a check. Figs. 9 to 14 give specimens of such diagrams.

Figs. 9 and 10 are diagrams taken at the Reading Water Works before and after inspection by aid of the Tylor district meter. Population, 8115; houses, all with water-closets, 1643; external stop-cocks, 688. Figs. 11 and 12 are diagrams taken at the Lambeth Water Works, district No. 1, before and after inspection with the Tylor meter. Fig. 13 is a night-inspection diagram with a Tylor meter, showing the result of each street being shut off in succession, as described above. Fig. 14 is a diagram taken from one district, of about 800 persons, in the Bridgwater Water Works, which were designed by Messrs. Hawksley. This diagram show a remarkable absence of waste.

Table XII. shows the results of inspection by the Lambeth Water Works in eighteen districts, and for a population of 37,683. All houses except 161 have external stop-cocks. Deacon's meters are used, and in district No. 1 Tylor's meter is also used.

Table XIII. shows the respective amounts of water pumped at Reading in January 1881 and 1882; five districts, containing about 8000 persons, have been or now are under inspection by the Tylor

meter. The details of the results in four completed districts have been furnished by Mr. Walker, the acting manager.

House Meters.—The general question of the introduction of meters for domestic supply in England is a very large one. Into its financial and economical aspects the writer does not propose to enter; but only to point out the great advantage of meters as a means of preventing waste, and thereby of increasing the efficiency, and diminishing the cost of the service, under whatever system that service may be administered. Tables IV. and V. show the consumption of water respectively in a shop and in a dwelling house; the rents are the same, and the water-rates £10 and £11 5*s.* respectively, but the difference in consumption is enormous, forming a tax on trades under the rating system. If the water companies were willing to grant supply by meter instead of by rate, there would be no difficulty in arranging existing meters to fulfil any conditions necessary.

In some of the recently erected workmen's dwellings, furnished with Tylor's "waste-not" fittings, it has been ascertained that the total consumption of water, including washing of clothes, does not exceed 6 gallons per head per day; and this it must be remembered is for the better class of artizans. The author has himself made many experiments on this point, and whilst the differences in consumption, in houses of the same class, are found to be very large, it is clear that 6 gallons per head is really sufficient. Tables VII. and VIII. give two cases of this kind, in houses of very similar character. The large fluctuations from day to day will be remarked, and also the fact that in the one case the consumption per head per day was $14\frac{1}{3}$ gallons, and in the other 4 gallons only. In the latter case however there was also a small rain-water cistern in use. Again, in houses of the middle classes, it is known that the quantity of water actually used for cooking, washing, and all other purposes except baths, is not more than 10 gallons per head per day, and for baths 5 gallons per head will be a very ample allowance. It will therefore be on the safe side to assume that the actual daily consumption per head for all purposes should not exceed 15

gallons for medium-sized houses, and 10 gallons for small; making in the latter case a large allowance for the increased consumption in single tenements, as compared with dwellings in flats. But it is known that the London waterworks supply on an average upwards of 27 gallons per head of the population; so that it appears that nearly half the total supply is absolutely wasted.

If by a proper system of domestic meters this enormous waste could be checked and brought within proper limits, the advantages, both to the water companies and to the consumer, must obviously be great. The increased pressure and service, resulting from the diminished drain on the mains, would enable a constant supply to be maintained at the top of every house throughout the day; and would thus do away with the need of cisterns for storage, which are always stagnant and often polluted. To the companies, the reduction in the cost of pumping and other expenses would pay for the whole expenses of supplying and maintaining the meters, and leave a very large surplus.

For instance, the report of the Committee in 1880 shows that the average gross income of all the London waterworks is at the rate of less than 7*d.* per thousand gallons, and that the trade supply is about one-fifth of the whole. Now if the income were raised by a charge of 1*s.* per thousand gallons of measured water, divided into average charges of 6*d.* for trade and 1*s.* 2*d.* for domestic purposes, it will be seen that the water companies of London would (if waste in the mains were limited to 8 per cent.) obtain additional profit to the extent of 4*d.* per thousand gallons supplied. On the other hand (as shown by Table VII.) even the most extravagant consumer would for an efficient supply pay less than he now does, as long as his fittings were in good order; and if his fittings were out of order, he, and not the water company, would pay for the wasted water.

APPENDIX.

TABLE I.—Tests of Meters for Accuracy.

Test of ½-in. Tylor Meter, No. 12447 ; *before fixing, Nov.* 16, 1877.

Head in feet.	Gallons of water run.	Rate, gallons per hour.	Error per cent.	Remarks.
136	220	744	5·1	Outlet controlled by diaphragms.
	,,	585	1·2	Do.
	,,	281	2·8	Do.
	,,	161	2·6	Do.
	,,	101	6·7	
	,,	81	0	
	,,	62	4·9	
	,,	46	4·9	
	,,	31	7·4	
	,,	19	8·9	
	,,	259	2·4	Test after trial, Oct. 15, 1879.

Test of ½-in. Tylor Meter, No. 12457 ; *before fixing, Feb.* 20, 1877.

Head in feet.	Gallons of water run.	Rate, gallons per hour.	Error per cent.	Remarks.
136	220	983	1·4	
	,,	544	2·3	
	,,	304	5·8	
	,,	220	2·0	
	,,	152	3·6	
	,,	99	4·5	
	,,	55	3·8	
	,,	40	5·2	
	,,	21	2·8	

N.B.—The efficiency shown in this Table is considered in Germany and France sufficient for domestic supply.

TABLE II.—TESTS OF METERS FOR ACCURACY.

Test of ½-in. Tylor Water Meter, No. 12457.

Before fixing, Aug. 30, 1877.		
Gallons of water used.	Rate, Gallons per hour.	Error per cent.
220	871	0·3
,,	645	0·7
,,	455	2·0
,,	301	2·9
,,	161	1·3
,,	81	5·5
,,	62	3·1
,,	31	1·2
,,	19	0·7
,,	12	6·1

Test of ¾-in. Tylor Water Meter, No. 12406.

Before fixing, Nov. 19, 1877.			After fixing, June 25, 1879.		Remarks.
Gallons used.	Rate, Gal. per hour.	Error per cent.	Rate, Gal. per hour.	Error per cent.	
220	1399	3·4			Outlet controlled by Diaphragms.
,,	823	1·4			
,,	638	4·7	456	1·1	
,,	301	0·3			
,,	161	8·2			
,,	101	3·1			
,,	81	4·4			
,,	62	4·4	58	1·1	
,,	46	4·6			
,,	19	9·2			
,,	12	9·8			

TABLE III.—ROTARY AND PISTON METERS.

Experiments carried out at the Lincoln Water Works, with constant service, showing the relative monthly registration of a Rotary and a Piston Meter.

Month, 1880.	Tylor Rotary Meter, Gallons per diem.	Kennedy Piston Meter, Gallons per diem.
March . . .	97	96
April . . .	102	101
May . . .	199	177
August . . .	83	77
October . .	90	86
Total for 5 months	19,575 Gal.	18,188 Gal. (7 % less)

The consumption in this experiment corresponds with that of an ordinary workman's house in London, with constant supply, containing 8 persons, and using on an average 13·07 gallons per head per diem.

TABLE IV.—ROTARY AND PISTON METERS.

Experiments with Rotary and Piston Meter, both ½ in., on a house and tobacco shop, containing 8 persons, of whom 3 were away from 6 A.M. to 6 P.M.: 1 bath; 2 w.c.'s.

Date.	Tylor Rotary Meter. Average Supply. Gallons per diem.	Frost Piston Meter. Average Supply. Gallons per diem.
1880. Dec. 23–26 . .	117	115
Dec. 27–30 . .	182	195
1881. Dec. 31–Jan. 3 .	152	138
Jan. 4–Jan. 7 .	122	118
Jan. 8–Jan. 11 (Frost)	145	122
Jan. 12–Jan. 14 (Severe frost)	166	150
Average. .	147	140 (4·75 % less)

N.B.—On January 14 the pipes were frozen, and remained so till Feb. 8, when the piston meter was found to be burst. The rotary meter recorded 240 gallons on Feb. 9, and 100 on Feb. 10.

This case represents a large class of houses used as small shops, with two or three lodgers besides the family. The average consumption is 17·75 gallons per head per diem. Water-rate £10.

TABLE V.—Rotary and Piston Meters.

Experiments with Rotary and Piston Meter, on supply of a house in the Chelsea district. Number of family 12 *to* 14 *persons ;* 2 *baths ;* 4 *w.c.'s. Supply constant during day-time.*

Date 1881.	Tylor Rotary Meter. Gallons per diem.	Kennedy Piston Meter. Gallons per diem.	Remarks.
Feb. 17 . .	150	Out of order	14 persons in house.
,, 18 . .	915	Do.	Do. Do.
,, 19 . .	945	Do.	Do. Do.
,, 22 . .	940	Do.	Family left.
,, 23 . .	300	290	Cleaning.
,, 24 . .	615	550	Cleaning, family returned.
,, 25 . .	535	500	Family left.
,, 26 . .	450	410	Leaky ball-valve repaired.
,, 27 . .	423	405	
,, 28 . .	423	405	Family returned.
March 1 . .	474	470	12 persons in house.
,, 2 . .	530	490	Do. Do.
,, 3 . .	415	400	Do. Do.
,, 4 . .	513	490	Do. Do.

This was a house occupied by a Member of Parliament, at a rent of £350 per annum. The average consumption, from Feb. 23 to April 11, was at the rate of 22·5 gallons per head per diem. But previous to repair of fittings on Feb. 26, the average consumption was at the rate of 31·3 gallons per head. Water rate £11 5*s*.

TABLE VI.—ROTARY AND PISTON METERS.

Experiments with Rotary and Piston Meters carried out by Mr. Coyne, Engineer of the Edinburgh Water Works, for his own information. The meters were placed on a public service and close together. Constant service.

No. of Trial.	Duration of Trial.	No. of Days.	Tylor Rotary Meter.	Piston Meters.	
			Gallons registered.	No. 1. (Frost) Gallons registered.	No. 2. (Kennedy) Gallons registered.
1	April 23, 1879 to Feb. 14, 1880	297	150,050	not fixed	164,600
2	Feb. 15, 1880 to June 3, 1880	109	46,200	not fixed	50,900
3	June 3, 1880 to Aug. 16, 1880	74	47,700	54,000	52,650
4	Oct. 27, 1880 to Feb. 19, 1881	116	34,160	36,100	38,800
Total	April 23, 1879 to Feb. 19, 1881	596	278,110	—	306,950

TABLE VII.

Quantities of water registered by a ½-in. Tylor Rotary Meter, in a house containing 5 people; all washing done at home; 1 bath; 1 w.c. Intermittent supply.

Date 1880.	Gallons consumed per day.	Gallons per head per day.
Sat. Nov. 20 .	210	42
Sun. „ 21 .	60	12
Mon. „ 22 .	90	18
Tues. „ 23 .	50	10
Wed. „ 24 .	40	8
Thur. „ 25 .	50	10
Fri. „ 26 .	60	12
Sat. „ 27 .	80	16
Sun. „ 28 .	60	12
Mon. „ 29 .	50	10
Tues. „ 30 .	60	12
Wed. Dec. 1 .	50	10
Thurs. „ 2 .	40	8
Fri. „ 3 .	310	62
Sat. „ 4 .	90	18
Sun. „ 5 .	50	10
Mon. „ 6 .	90	18
Tues. „ 7 .	60	12
Wed. „ 8 .	250	50
Thurs. „ 9 .	30	6
Fri. „ 10 .	60	12

N.B.—3010 gallons consumed in 6 weeks, ending Dec. 10. Daily average 70⅓ gallons, or 14⅓ gallons per head. Rent of house £40 per annum; water-rate 41*s*. Water used by meter in six months 13080 gallons, which at 1*s*. 2*d*. per thousand is equal to 30*s*. per annum. On Nov. 20, Dec. 3, and Dec. 8 the cistern was washed out.

TABLE VIII.

Quantity of water registered daily by a ½-in. Tylor Rotary Meter, fixed in a house in the Lambeth district, containing 7 *rooms:* 1 *w.c.; garden* 120 *ft.* × 16 *ft. All washing done at home. Number of family,* 6.

Contents of cistern 7·7 *cub. ft., or about* 50 *gallons. Intermittent supply, from Southwark and Vauxhall Company. There is also a rain-water tank, containing about* 50 *gallons, which is used when available. Meter fixed* 26*th August,* 1880; *cistern then empty.*

Date 1880.	Gallons consumed per day.	Gallons per head per day.	Remarks.
Aug. 27 . .	30	5·0	
„ 28 . .	15	2·5	
„ 29 . .	10	1·66	
„ 30 . .	70	11·6	
„ 31 . .	25	4·1	
Sep. 1 . .	30	5·0	
„ 2 . .	35	5·63	
„ 3 . .	60	10·0	
„ 4 . .	60	10·0	
„ 5 . .	15	2·5	
„ 6 . .	30	5·0	
„ 7 . .	0	0·0	Not turned on.
„ 8 . .	5	0·83	Plenty of Rain Water.
„ 9 . .	3	0·50	Do.
„ 10 . .	2	0·33	Do.
„ 11 . .	18	3·0	
„ 12 . .	2	0·33	Plenty of Rain Water.
„ 13 . .	30	5·0	
„ 14 . .	18	3·0	
„ 15 . .	17	2·8	
„ 16 . .	5	0·83	
„ 17 . .	20	3·3	
„ 18 . .	10	1·66	
„ 19 . .	10	1·66	
„ 20 . .	25	4·1	
„ 21 . .	35	5·80	
„ 22 . .	10	1·66	
„ 23 . .	5	0·83	Only one at home.
„ 24 . .	20	3·3	
„ 25 . .	10	1·66	
„ 26 . .	25	4·1	
„ 27 . .	25	4·1	
Total . .	670	4·0	Average.

TABLE IX.

Monthly Returns for same house as in Table VIII.

Date of Measurement.	Gallons per month.	Gallons per head per day.	Remarks.
1880. Sept. 27	670	4·0	
„ Oct. 25	760	4·5	{Cistern tested 50 gallons Meter gave 48 „
„ Nov. 22	660	3·9	
„ Dec. 20	815	4·8	
1881. Jan. 17	805	4·8	
„ Feb. 14	650	3·8	
„ Mch. 14	889	5·2	
„ April 11	881	5·2	
„ May 9	955	5·7	Leaky pipe noticed.
„ June 6	1045	7·4	One person died.
„ July 4	934	6·6	
„ Aug. 1	1170	8·3	
„ Aug. 29	629	4·5	Leak stopped.
1882. Jan. 12		8·0	* Ball valve leaking.

Average consumption for 12 months, per head per day, 5·1 gallons, exclusive of rain-water.

* After Aug. 29 the ball valve was made to leak a stream about the size of a straw; and on Jan. 12, 1882, the further consumption was found to be 5,600 gall., equal to 8 gall. per head per day during this time.

TABLE X.

Six months' comparative experiments at a urinal—West Middlesex Waterworks—Siemens and Tylor Meters on same main.

Date taken.	Siemens Meter. Gallons each month.	Tylor Meter. Gallons each month.	Difference per cent.
1881.			
June 14 .	3,800	3,800	0
July 11 .	4,800	4,600	4¼
Aug. 16 .	22,800	23,100	1½
Sept. 17 .	2,000	2,000	0
Oct. 20 .	3,000	3,000	0
Total	36,400	36,500	0·3 Average.

TABLE XI.

Six months' comparative experiments at a laundry—West Middlesex Waterworks—Siemens and Tylor Meters.

Date taken.	Siemens Meter. Gallons each month.	Tylor Meter. Gallons each month.	Difference per cent.
1881.			
May 14 .	29,600	28,900	2½
June 14 .	27,000	30,000	10
July 11 .	27,100	26,500	2½
Aug. 16 .	36,900	38,800	5
Sept. 17 .	35,000	36,700	5
Oct. 22 .	41,000	42,000	2½
Total	196,600	202,900	3¼ Average.

TABLE XII.—District Meter System.

Town District, Lambeth Water Works.

Result of inspection with Deacon Meters.

Number of Meter Districts inspected.	Population supplied.	Consumption per head per day Before inspection. Gallons.	Consumption per head per day After inspection. Gallons.	Saving per head per day. Gallons.
18	37,683	35·4	14·1	21·3

There are altogether 44 meter districts in the town district. Up to the present time 18 of these have been actually placed under the district meter system, a Deacon waste-water meter being fixed for each. The average consumption in the 26 unworked districts is 32·6 gallons per head per day.

The staff consists of four waste inspectors, two at 40*s.*, and two at 35*s.* a week; and four labourers at 4*s.* per day, or 6*s.* if on night inspection.

The population supplied under the Deacon waste-water meter system is 8 per cent. of the whole population supplied by these waterworks. External stop-cocks have been fitted to all houses in the above 18 districts, except 161. The reduction in pumping expenses is not yet apparent.

TABLE XIII.—DISTRICT METER SYSTEM.

Reading Water Works. Results of inspection with Tylor Meters. Constant service.

Name of District.	Extent of District.			Outside Stop Taps.	W.C.'s with cisterns.	Consumption per head per day.		Causes of Waste.
	No. of Streets.	No. of Houses.	Population.			Before inspection.	After inspection.	
	No.	No.	No.	No.	No.	Gallons.	Gallons.	
Weldale Street	5	211	1055	95	208	60·00	16·00	Breakage of 3-inch main, passing over a drain.
Great Knollys Street...	1	176	880	72	179	27 61	9 20	Leakages at ball and bib taps.
London Road............	9	392	1660	140	121	12·65	10·24	Leakages at ball valves.
Addington Road	7	370	2050	94	390	15·61	7·04	Grammar School urinals left running all night.
Bath Road	13	494	2470	287	494	24·29	...	Inspection not yet completed.

The saving effected on the four districts in which the inspection is completed is found from this Table to amount to upwards of 80,000 gallons per day, or 58 per cent. of the supply before inspection. The quantity of water pumped in the month of January 1881, before inspection, was 49,287,000 gallons; and in January 1882, after inspection, 46,242,000 gallons; showing a decrease of 3,045,000 gallons in the month. The smaller quantity also supplied 536 new services, which had been laid in the course of the year 1881. The consumption given in this Table includes trade supplies, excepting those which were already furnished by meter.

Discussion on Water Meters.

Mr. TYLOR exhibited specimens of the Kennedy meter, the Frost meter, the Siemens meter as made by Messrs. Guest and Chrimes, Messrs. Siemens and Halske's meter as used principally in Germany, and Messrs. Tylor's meter; all those shown being ½-inch meters capable of passing about seven hundred gallons per hour as a maximum. He also showed a larger Tylor meter, 4 in. diameter, connected with clockwork on the "district-meter system," and capable of passing about thirty times that quantity of water.

He wished to add a few words in explanation of the "district-meter" diagrams, Figs. 9–14, Plate 4. They were produced by a meter connected with a clock similar to that on the table, and they represented the amount of water passing through the mains of different districts during all hours of the day and night. In Fig. 9 the registration began at eight o'clock in the morning, and went on, hour by hour, throughout the whole twenty-four; and it would be noticed that large differences occurred in the distances between the upright bars which marked the consumption of a certain quantity of water, as had been described in the paper. The pencil made its transverse or vertical movement in accordance with the flow of water; but the longitudinal or horizontal movements of the paper ribbon, due to the clock, took place suddenly every two minutes, and formed the small steps that could be seen on the diagrams. As soon as the pencil had reached the upper side of the paper, it was released by the meter, and returned suddenly to the bottom, forming a straight line across the ribbon of paper. The interval between any two successive lines represented therefore a complete revolution of the cam which gave the transverse motion, and represented consequently whatever amount of water the meter was set for—with the smaller sizes 500 gallons, and with the larger sizes 1000 gallons.

The diagram, Fig. 9, Plate 4, was the most perfect he had yet obtained. It was taken from a district of the waterworks at Bridgwater which waterworks had been constructed by Mr. Hawksley; and it

would be seen how very characteristic was the movement of the water which took place. From 8 o'clock in the morning to 11, the flow was irregular, but continued at about 500 gallons an hour. Between 11 and 12 a considerable increase of speed took place, because people were coming home about the middle of the day and using more water; hence the next 500 gallons were measured in about three-quarters of an hour. After 12 o'clock the consumption went on more slowly, and in the afternoon it got down to a very low flow indeed. Usually in waterworks there was more water used in the evening, but he had six or eight of these Bridgwater diagrams all confirming one another, so that no doubt the small consumption in the evening was correct. After 8 o'clock very little water was used at all, and the flow dropped down soon afterwards to nothing, and continued at nothing the whole of the night; showing that the mains were absolutely sound, and that no water was running to waste. At 5 o'clock in the morning the flow began again, increasing faster after 6 o'clock, and after 7, until it got back to the same speed at which it commenced on the previous day at 8 o'clock. The consumption of the whole town had been checked by Mr. Parker, the resident engineer, by leaving the reservoir alone to give the whole supply during a week; the consumption of the whole town was then found to be about 7 gallons per head per day, corresponding nearly with the diagram shown from one district.

Next he would point out that the diagram Fig. 13 showed exactly the reverse of the foregoing: and that in wasteful waterworks more water actually ran during the night, and especially in the small hours of the morning, than during the daytime—the reason being, he supposed, that the pressure was higher at those times than when all the people were using water. The diagrams, Figs. 10 and 11, showed the waste in the mains of one of the London waterworks, in a district of about four thousand people, before and after inspection had taken place. These diagrams showed the variation caused by consumption; thus between 1 and 2 o'clock in the early morning a sudden rise took place. That was acounted for by the fact that there was an omnibus yard, where the horses came back at that time; and an extra 100 gallons of water in excess of the normal flow was drawn

for watering these horses. After 2 o'clock the flow continued very regularly indeed, at the rate of about 1000 gallons an hour, until 7 o'clock, when the speed got greater for ordinary consumption.

The method referred to in the paper for inspecting waterworks districts, first brought into practice by Mr. Deacon, was illustrated by the diagram, Fig. 12. A district was first separated, by means of sluice valves, from the rest of the districts supplied by the water works; a meter was put on the main controlling that whole district, and at 12 o'clock at night, or even earlier, inspectors went round the district and shut off in succession, at convenient intervals, all the different streets abutting on that main. The result of each street being shut off was shown on the diagram by the change in direction of the lines showing the total flow. Each street was marked by the inspector with the time at which he shut it off; so that he had, on referring to his diagram in the morning, a record of what difference the shutting off of each made in the total flow, and by that means he knew where to look for the waste. He then went round at night to all the houses in any street that was marked as wasteful, and listened at the stop-cocks to hear whether water was running. He marked the houses where he heard the noise, to be examined the next day, and gave notice to the inhabitants to stop the waste. By turning off all the stop-cocks in a street, and taking another diagram, it was ascertained whether the waste was in the street main and services. In cases where there were no stop-cocks outside the houses, he could not listen outside, and had to make a house-to-house inspection. The only way to examine successfully with the district meter in such cases was to make the districts very small, so that they could be kept under control; but in the large districts in London, of 5,000 inhabitants, each separate house ought to be controlled by a stop-cock outside.

Mr. W. ANDERSON said it had been his duty in connection with the Antwerp waterworks to determine what kind of meter he should recommend the company to adopt; because unfortunately, in the arrangement made with the municipality of Antwerp, there was no provision for a minimum charge. Now their friends across the

Channel were generally quick to find out in what way they could obtain water at the least possible charge; and therefore, as the supply was constant, it was necessary to recommend a meter that would not pass even a very small quantity of water without registration. Consequently a number of experiments were made at the Erith Iron Works, with all kinds of meters, to determine which were most likely to give a faithful record, even under very small flows of water; and Figs. 15 and 16, Plate 5, gave the substance of the experiments made, of which the actual record was given in the Table, page 68. The figures on the horizontal line gave the measured delivery in each experiment in gallons per hour; and the points on the vertical lines showed the quantity of gallons that were registered by the various meters. The fine diagonal line at 45° showed the delivery of a perfect meter, this line passing through all the points of intersection of the horizontal and vertical lines; and the other diagonal lines showed the divergencies of the meters tried. All the meters were new, as sent in by their makers. Two kinds of piston meter were tried: the Kennedy meter, and a meter made by a Belgian manufacturer named Galasse. The latter was a very ingenious meter, and was constructed upon the principle of a pumping engine exhibited in 1862. It consisted, as shown in Plate 6, of two double-acting water-cylinders D D, fitted with pistons E E and piston-rods F F. Water was admitted through ordinary three-ported slide-valves G G, which were actuated by the piston-rods of the alternate cylinders, *i.e.* the piston-rod of the first cylinder actuated the valve of the second, and *vice versâ.* The motion of the pistons was transmitted to the counter-gear by means of a crank H, which caused a crown ratchet-wheel K to reciprocate, and to actuate a pawl J hanging down from the first-motion wheel of the counter-gear L. The piston and all the glands were packed with leather rings. Steam pumps on this principle had been invented in America, and first shown in 1862 at the London Exhibition. Since that time he had himself made a great number for small water supplies, and for working hydraulic machinery at high pressure. The steam cylinders and pumps were arranged in line, and connected to a common piston-rod; and steam was admitted by slide valves actuated by the pistons of the alternate cylinders. There

TABLE A.—EXPERIMENTS WITH WATER METERS.

Under a pressure of about 100 ft. of water, or 44 lbs. per sq. in.

Name of Meter.	Size.	Quantity which will pass the Meter without Registration.	Experiment with about 30 gals. per hour.					Experiment with about 120 gals. per hour.					Experiment with about 600 gals. per hour.				
			1 Time.	2 Actual discharge.	3 Registered discharge.	4 Error per cent.	5 Actual discharge, Gallons per hour.	1 Time.	2 Actual discharge.	3 Registered discharge.	4 Error per cent.	5 Actual discharge, Gallons per hour.	1 Time.	2 Actual discharge.	3 Registered discharge.	4 Error per cent.	5 Actual discharge, Gallons per hour.
Ducenno	½ inch	Gals. per hour. About 25	h. m. 4 5	litres 545	litres 150	minus 72·4	29·4	h. m. 1 2½	litres 545	litres 510	minus 6·4	115·2	m. 38½	litres 1636	litres 1840	plus 12·4	561
Valentin	20 mm. ¾ inch	About 60	1 30	gals. 48	gals. 0	minus 100	32	2 7	gals. 240	gals. 257	plus 7·1	113·4	35	gals. 360	gals. 360	0	617
Galasse	½ inch	Practically 0	2 10	litres 273	litres 296	plus 8·4	27·7	0 31	litres 273	litres 275	plus 0·7	116	13	litres 273	litres 274	plus 0·37	277*
Siemens	½ inch	About 5	1 2	gals. 30	gals. 26	minus 13·3	29	0 32	gals. 60	gals. 57	minus 5·0	112	13½	gals. 90	gals. 85	minus 5 5	400*
Kennedy	½ inch	Practically 0	2 0	litres 273	litres 280	plus 2·5	30	0 39	litres 409	litres 420	plus 2 7	138	6½	litres 273	litres 280	plus 2·5	554
Berhaut	¾ inch	About 8 to 10	2 6	litres 273	litres 220	minus 19·4	28·5	0 42	litres 409	litres 420	plus 2·7	128	9¾	litres 409	litres 450	plus 10·0	554
Tylor	½ inch	About 5	3 13	gals. 90	gals. 80	minus 11·1	28	0 29	gals. 60	gals. 60	0	124	9½	gals. 90	gals. 89	minus 1·1	568
Meinecke	⅜ inch	About 30	2 3	litres 273	litres 0	minus 100	29	0 29	litres 273	litres 270	minus 1·1	124	10	litres 409	litres 400	minus 2·2	540*

* These three figures represent the utmost that the respective meters will pass with 100 ft. head.

were certain contrivances for preventing the pistons from over-running the stroke. The pumps were quite automatic, would start in any position, and could be stopped or varied in speed by shutting off or throttling the water delivered.

Those two piston-meters, the Galasse and the Kennedy, were practically perfect; that was to say, they never passed any water without registering, and at whatever rate within their powers the water was passed they registered correctly: so that on the diagram now exhibited it was not possible to show the minute variations observed. The Galasse meter was finally recommended, chiefly because it occupied a very much smaller space than the Kennedy, and worked very uniformly and quietly. Thus a jet taken for a garden hose, after going through the Galasse meter, was perfectly uniform and continuous, and the meter itself was perfectly noiseless in its action. On the other hand, the jet from a Kennedy meter was not continuous, because of the meter having only one cylinder instead of two. For that reason the Antwerp Water Works Company had adopted the Galasse meter for the smaller sizes; but for the larger sizes, so far as he knew, the Kennedy meter was used.

With regard to the inferential or turbine meters, they showed at low velocities a very great variation; but he was glad to have the opportunity of saying that certainly the best of the inferential meters he had tried was the Tylor meter. That meter passed only 5 gallons an hour without registering, and the line representing its registrations in Fig. 15, Plate 5, followed very closely the line of the perfect meter, right up to 550 gallons per hour. The next best was the Siemens meter, which was only wrong to the extent of 5 per cent. with the two higher flows in the Table, although with the lowest flow of 30 gallons per hour the divergence was rather greater. Other meters—the Berhaut, the Meinecke, and the Ducenne—allowed 10, 25, 30, and the Valentin meter allowed even 60 gallons an hour to pass through without registering anything at all; and the divergence at higher flows was very considerable. Evidently therefore meters of the turbine class required to be very carefully and accurately made, in order to be at all trustworthy.

With respect to the remark made in the paper, p. 46, that a certain inaccuracy arose from the turbine meter continuing to spin round after the supply had ceased, that was an important question, because in domestic service that was what naturally took place. A cock was opened for a short time, to fill a jug or pail, and then shut again. In such cases there was some delay in getting the meter to begin to indicate, and then the indication went on for some time after the flow had stopped. From experiments he had made, he found, in a Siemens meter, that practically the delay in getting into motion was exactly compensated by the time during which the meter continued to rotate after the supply of water had stopped; so that in practice that source of inaccuracy was removed.

The result of all the experiments had been, to his mind, that for constant service, and where there was no minimum charge, the proper plan was to adopt a piston meter for small domestic services; but for larger services, such as filling water-carts or ships' tanks—which latter was an important source of revenue to the Antwerp Water Works —the Siemens or any other good rotary meter was found to be the best, on account of its cheapness and handiness and the small space which it occupied.

Mr. Thomas Hawksley said that, although he had had fifty years' experience of water meters, he was still a learner on that subject. It had often been observed however that "history repeats itself." The inferential or turbine form of meter, which had been described, was, he believed, not less than from one hundred to two hundred years old. In his early days, sixty years ago, a sort of inclined vane used to be put in, in the midland counties, as a ventilator to workshops. This vane was turned by the current of air which impinged on its inclined surface, and it moved proportionately to the velocity of the wind. That was in fact the principle of the turbine meter. Afterwards the very same thing was used for shifting round the sails of a self-adjusting windmill, and it might still be seen in those counties in which the windmill was much used. An arm projected at the end of the windmill shaft, with an inclined vane upon it, which automatically moved the sails into the exact direction in which the

wind was required to impinge upon them. Those were cases of what might be called open turbines. In the case of the enclosed turbine, the same thing was done by impressing the force of the current of water on the oblique surface which was presented to it in the turbine-wheel itself. This wheel took precisely the place of the sails in the ordinary windmill. Now it was to be observed that the sails of a windmill revolved slower than the wind travelled past them, by reason of the frictional resistance of the grinding re-acting upon the sails. It was exactly the same in the turbine meters; and the consequence was that they were always disposed to go more slowly than the water which passed through them. Supposing a turbine meter at starting had no resistance at all, the revolution of the meter would be precisely coincident with the velocity with which the water passed through the openings; but as soon as friction came in, the motion was resisted, and the meter began to count less and less as compared with the quantity of water passing through it. At last the meter, through the increase of friction, generally caused by the deposition of calcareous or ferruginous salt—which was a very common incident,—actually ceased to revolve. But when the meter had ceased to revolve, the water still went through it at exactly the same rate as if the meter were in action; consequently the meter failed to register the quantity of water delivered to the consumer.

But, besides this, there was a trick of manipulation, which it was possible to adopt with such meters. If a consumer, possessing a cistern, chose to close the inlet cock nearly, so that only a very small quantity of water should pass in a given time, yet enough to give him all he needed when running for the whole twenty-four hours, then that class of meter, if it were subjected to any considerable or even appreciable amount of resistance, would allow the water to pass without any registration at all. In fact, although the turbine meter was a very excellent one for rapid flows, it was no meter at all with respect to very small flows, because any person using a meter of that description might draw a large quantity distributed over a long period of time without any registration at all. But for house consumption, and especially house consumption abroad, that was just the thing to be avoided; because continental consumers, as far as his

experience went, were exceedingly economical, and at the same time exceedingly clever, and by the kind of manipulation to which he had referred it was quite possible for them to carry off the entire dividends of the water company supplying them.

He would say nevertheless that the turbine meters were very valuable instruments in their way—for instance, for the supply of water-carts, where the water had to be drawn at great velocity and in a very short time, or for the supply of large consumers generally; exactly as they were bad for registering a very small supply, so they were good for a large supply and a high velocity.

He would now supply a little information which might be of value, inasmuch as there would probably be a discussion in Parliament as to the proper way in which cities ought to be supplied with water. With regard first to capital; they would be astonished to hear—but it was nevertheless true—that if companies were required to supply water by measure, the additional cost which would be imposed upon the population would be practically 50 per cent. of the entire cost of constituting waterworks without meters. That increase of cost—which included, in addition to the prime cost of the instrument itself, the expenses of fixing and of repairs, replacement every third year, testings from time to time, renewals, and official inspection and registration—was so monstrous that he did not think we should ever in this country come to be supplied with water for domestic consumption by means of meters. But the discussion might go further. If they were to have, as had been suggested by some persons, two kinds of water admitted to every house, there would be an additional amount of capital involved, in the supply of water by meter, almost equal to the whole sum upon which dividend was now paid by the companies for the supply they rendered without meter. He thought this was so absurd that, as practical men, they might dismiss the further consideration of that subject; although he was afraid it would still have to be considered amongst the unpractical men of whom the national Parliament was in the main composed.

But they had another class of meter before them, namely that which was now called the Parkinson meter, although, in point of fact

it was invented in the year 1825 by the predecessor of Mr. Parkinson, Mr. Samuel Crossley: so long ago was the subject of the supply of water by meter considered in this country. The Americans were not the first to invent the water meter. Of all the meters which had been invented, that meter (Figs. 1 and 2, Plate 1) was to the present day the most perfect. It was not however in all cases the most applicable; because, as the paper had stated, it required (being a low-pressure meter) to be placed at the highest point at which the water had to be supplied. In passing through that meter, the water, in point of fact, lost all the pressure which was previously impressed upon it in the supply pipe. But that meter, being actuated simply by the weight of the water which was passed through it, registered at every revolution a kind of annulus of water, the thickness of which was determined by the size of the trough in which the meter revolved. The meter therefore was, under ordinary circumstances, a means of registering with exceeding accuracy the quantity of water which passed through it.

There was again a third class of meter, which was not subject to the one defect of the Parkinson meter, namely that generally denominated the Kennedy meter (Fig. 3, Plate 1). That was a displacement meter. The water passed into a cylinder, exactly as the steam passed into the cylinder of a steam engine, and the registration was recorded simply by measuring the length of the stroke, and the number of strokes. It was a very excellent meter, but it had some singular defects. It sometimes happened that during the motion, water being a non-elastic substance, the tumbler C, which moved the four-way cock, stuck exactly at the top of its motion, instead of tumbling over as it ought to do. When it stuck at that point, the ports were open in both directions, and the water rushed straight through without actuating the piston at all; and in that condition of the meter the consumer got all the supply he required, without any registration whatever. However it was a very excellent meter if well looked after; but according to his experience it required to be attended to about once in a fortnight; if not, the result was that the water company suffered considerably.

There were other very grave considerations as to what would be the effect of the introduction of any system of meter in the supply of a town. In his opinion the effect of supplying water by measure, as milk was supplied, would be exceedingly detrimental to the health of the population. It would be found that the working class, and he was afraid the poorer classes generally, would be exceedingly stingy in the use of water, and that the change would by no means tend to the promotion of cleanliness. On that account, as well as on account of the enormous cost which would have to be incurred, he was, after long experience on the subject, utterly opposed to the often-suggested plan of supplying water for domestic consumption by measure.

There was however another consideration, which was a very important one for the water companies, namely the suppression of waste. It had been said that the suppression of waste must be effected by the introduction of some class of meter, accompanied by a great amount of midnight research. He could assure them that nothing of the kind was necessary. He had had the honour of making more than a hundred waterworks, and had frequently had the pleasure of changing an intermittent supply into a constant supply; and what had been the result? Generally speaking, this: that where the intermittent supply required the daily delivery of from thirty to forty gallons per head, the constant supply, without the introduction of any meter system at all, but with the necessary care as to the arrangements of the internal fittings of the houses, had been reduced to from fifteen to twenty gallons per head. In the case of Sheffield, only a few years ago, when the supply was intermittent, the consumption of that town, with 300,000 inhabitants, was 38 gallons per head per day. Rules and regulations were obtained under the authority of Parliament, and the intermittent supply was changed into a constant supply, so that every person could draw what water he liked at every hour of the day or night; and at the present moment the consumption—including the trade consumption, which, as might be supposed, was a very considerable one—had been reduced from 38 gallons to 17 gallons. No night-work and no meters had been found to be necessary in that town. In Nottingham the consumption (with about one quarter of the water supplied for trade purposes) had been also

maintained at about 17 gallons. In Norwich the consumption was formerly about 40 gallons per head per day, and the supply became exhausted by 8 o'clock at night. The company were bound to a constant supply, which however they could not afford; and a staff of men was therefore obliged to be kept at the police office, to be ready for service in the case of a fire breaking out during the night. A proper system of rules and regulations, not in the least interfering with the proper rights of the consumers, was introduced, and the consumption fell, without any shutting off at night, to 15½ gallons. In London the companies, during their present one or one and a half hour of delivery per day, or perhaps even less, were furnishing about 32 gallons per head per day; and he had no hesitation in saying that one half of that quantity of water ran to waste, and that if this waste were prevented the water need never be shut off either day or night.

Mr. FREDERICK NEWMAN said, without entering into the question of the relative values of meters, he should like to place before the meeting some experience he had had in a town in South America. Out of 4,480 services, there were 2,638 on the meter system, and 1,842 on the ordinary rating system. The adoption of the meter had been at the request of the inhabitants, and it had been perfectly satisfactory in every respect; in fact, the rentals obtained from the payments by meter, as compared with those by rating, were as 39 to 23. The meter system was first tried in order to prevent waste. The system of free flow had previously been tried, but there were so many objections to it, and so much inconvenience had been experienced, that it had been found necessary to adopt the system of supply by meters. All the meters mentioned in the paper were there in use; and according to the last accounts, Kennedy's, Tylor's, and Siemens & Halske's were preferred. Of Frost's meters he had had no experience. Prices certainly came out very much higher abroad than in England; but judging by his experience the London companies would have to raise their rates very considerably, something like threefold, if they supplied by meter, in order to pay the same dividends as they now paid. The waste at the town he

referred to had been very large, nearly 50 per cent. They had endeavoured in every way to prevent it, and by the system of meters they had brought it down considerably. Extensions were about to be carried out, by which they hoped to have the whole consumption regulated by meter.

Mr. W. E. Rich said the accaracy of inferential meters for small flows must not be judged only by their registrations when new, as tried with a testing tank or otherwise, since all such meters were very liable to become hampered by the accumulation of deposit upon them, and if, from the disuse of water, they were once allowed to stop for a few weeks, it was almost impossible to get them to start again satisfactorily. In London, where inferential meters were used almost universally in cases of meter supply, the rule was to change them about every two years; and he should think the probability was that in the second year of their working the results they gave for small flows of water were very deficient, and prejudicial to the water companies. Most of the large waterworks on the Continent —among them those of Berlin, St. Petersburg, and Odessa—used inferential meters of the Siemens and Halske type, which was closely allied to the Siemens meter made in England. The same meters had also been used in Paris and Brussels. But it was found on enquiry that, where the supply of water was getting deficient and barely up to the demands of the town, the water companies or other authorities were now setting their houses in order, and, being obliged to supply by meter, they were compelled to adopt the positive instead of the inferential meter. That had been the case of late years in Brussels, where they had now about 2000 Galasse meters in use, and 3000 Kennedy meters: all the others were gradually being exchanged for these. In Paris, within the last two years, a commission had reported on the subject, and the municipality had decided that in future every private consumer in Paris must take water by meter. Four different patterns, all of the positive type, had been approved, and no other type would be admitted: so that, after sufficient time had been allowed to replace them, not one inferential meter would be permitted to serve water in Paris. Of

the four meters selected, three were by French makers—namely Frager, Desplechin-Mathelin, and Samain; but he was glad to say that one English meter—the Kennedy—had been approved, and he believed the firm were starting a small factory in Paris at which to make them.

With regard to clockwork registering meters, which the paper had mentioned, referring also to Mr. Deacon's meter which had been used with so much success in Liverpool and Glasgow and one or two other places, it had occurred to himself, having watched the introduction of that class of meter for several years past, that it would be a great advantage if the clock could be easily disconnected from the meter, and carried about in a case like a steam-engine indicator. It could then easily be fixed to one meter for a day or two, and then taken away to another, instead of being left permanently upon one meter in one street. There was a great deal of delicate clockwork necessary in an apparatus of that kind, and it was a mistake to load a water company with the expense of a large number of such instruments, which frequently need not be used at all for months together. It was only when a district was suspected of waste that the clockwork need be put on and diagrams taken. The labour of detecting waste might be very much reduced by that system; the number of instruments might be reduced, and yet equally valuable results obtained.

Mr. ARTHUR PAGET observed that Mr. Hawksley had commenced his speech by the remark that "history repeats itself." He had not had the benefit of Mr. Hawksley's long experience in mechanical subjects; but old friends of his had related to him, when a boy, how the gas meters, which had then been newly introduced, had been abused, and how a long bill of indictment had been drawn against them, just like that which Mr. Hawksley, with so much talent and perspicacity, had drawn against water meters. What would be thought of any engineer who now advocated the use of gas by any other system than meter? If their forefathers drew up such a long bill of indictment against the use of gas by meters, from their being so imperfect, so impossible to keep in order, so in the habit of

robbing the gas companies as they were supposed to be, he ventured to think that subsequent generations might wonder how their ancestors of the present day could have hesitated before adopting the common-sense system of letting those who used water pay in proportion to the quantity they used.

There was one other point in Mr. Hawksley's speech about which he was somewhat puzzled. If he understood Mr. Hawksley rightly, he had stated that, if the system of water meters were adopted, the cost of plant, from the commencement of the water supply to the tap out of which the consumer got it, would be increased by 50 per cent.; and he presumed that—as Mr. Hawksley, in common with almost every one else, on sanitary if not on stronger grounds, advocated a constant supply—it was to a constant supply that he referred. He happened however to have some evidence to lay before the Institution, which would rather lead to a different view of the question as to the cost of the use of water meters. He had recently built a house in a town where there was a constant supply at a pressure of 40 lbs. per sq. in. He had the plans and estimates made out for the fittings, on the plan of paying by rate, and the cost rather astonished him. He then applied to the waterworks for permission to pay by meter: but they said that they would not allow him to do so. He was told however that there was a clause in the Act by which, if he were to put down a water engine, they would be compelled to supply by meter; and by threatening to put down a cheap water engine (in which case they would have no choice) he induced them to consent to supply him by meter. He accordingly arranged for a supply by meter; and the contract (owing to the absence of cisterns and ball-taps, and to the cheaper nature of the fittings) came to rather less than half the other contract: so that instead of an increase of 50 per cent. there was a diminution of 50 per cent. in the expense to the proprietor of the house.

He thought they ought to thank Mr. Tylor for having driven an additional nail into the coffin of the water-rate system, by bringing forward a useful meter, though it might not be absolutely reliable in the supposed case of such small supplies as five gallons an hour, which in England (with English habits and fondness for water) might be

almost put out of the question. He ventured to think that, although Mr. Hawksley had spoken so strongly against the system of meters, more and more companies would be advanced enough to follow the example of Paris and other continental towns, and to decide that water, like gas, should be supplied only by meter.

Mr. Hawksley asked permission to add a word in explanation. His friend Mr. Paget had unfortunately omitted the cost of all the reservoirs, all the main pipes, and all the apparatus established by the company; he had only taken into account the cost of his own individual water supply, from the main of the company to the tap in his own house. That, he ventured to say, had little or nothing to do with the subject. The total cost to a water company might amount, in the case of gravitation works, to £5 per head of the population, sometimes reaching £15 or £20 per head. But the cost to the consumer of introducing the supply into his own house was a very insignificant fraction of that. He still repeated that, if meters were required to be used for domestic consumption, the water company would have to go to a cost which would virtually add 50 per cent. to their capital without water meters; and this had nothing to do with the cost of the introduction of water from the company's main into the house of the consumer.

Mr. H. J. Chaney said the question had been asked, what amount of error might be expected in water meters? That he found to be a difficult question to answer, for the experiments hitherto made were misleading. In some instances he found that meters could not be depended upon within 15 per cent., although in other cases makers stated that their meters gave accurate results. The difficulty of finding what was the actual percentage of error in meters was even shown in Mr. Tylor's valuable paper. For instance, in the author's own experiments, which no doubt could be relied upon, it had been found that piston meters registered sometimes 6 per cent. less than rotary meters; whereas the engineer to the Corporation of Edinburgh found that piston meters registered 9 per cent. more than rotary meters. He did not know what kind of meters had been

selected in each case, but he mentioned the fact to show the great difficulty of finding out the percentage of error in meters. So far as his own experience went, he was disposed to place the average percentage of error—in good meters, carefully tried under different conditions, whether under constant or intermittent supply, or at different temperatures, or with regard to different qualities of water—at 7 per cent. He did not know how far it might be possible to get further information with regard to the amount of errors in meters, which was really the main point that had hindered the more general adoption of meters in the metropolis for domestic purposes. The question of providing a water meter, not only for large trade supplies, but also for domestic purposes, of accuracy sufficient to bring it within the reach of legislation, had, he thought, not yet been solved.

Mr. R. PRICE WILLIAMS had heard with much regret that the introduction of water meters for domestic supply was regarded so unfavourably by so eminent an authority as Mr. Hawksley; because in London at the present moment, as they were all aware, the water question was assuming great importance. They heard from the same eminent authority, as well as from the author of the paper, that the supply per head per day, instead of being 32 gallons, ought only to be 15 gallons, or say 45 per cent. of its present amount; and it would be found further that the total quantity of water supplied per day, as given in the return for 1879, amounted to no less than 51,187,000 gallons; and the average gross receipts of the eight water companies of London amounted roundly to $6\frac{3}{4}d.$ per thousand gallons, as shown by the tabular statement annexed. Hence if by the adoption of the meter system the present enormous amount of waste could be prevented, it would represent an available daily supply of 28,152,850 gallons, which would be sufficient to provide for some time for the increased supply required to meet the constant and rapid increase in the population of London and its suburbs; and the commercial value of this further available supply, if estimated at $6\frac{3}{4}d.$ per thousand gallons, would alone amount to £288,444 per annum. He could not but think that this enormous amount of waste ought to be stopped; and in that case he considered

Cost per Million and per Thousand Gallons, based upon the average of the nine years 1871–1879, *of the Water supplied by the Eight London Water Companies.*

	Cost per Million Gallons.	Cost per Thousand Gallons.	
	£ and decimals.	£ and decimals.	*d.* and decimals.
MAINTENANCE:—			
Collection	0·390	0·000390	0·096
Distribution	1·510	0·001510	0·370
Pumping	2·888	0·002888	0·707
Filtration	0·333	0·000333	0·081
Salaries..	0·959	0·000959	0·235
Rent	0·449	0·000449	0·110
Thames Conservancy	0·317	0·000317	0·078
Rates and Taxes	1·726	0·001726	0·423
Total	8·572	0·008572	2·100
MANAGEMENT:—			
Allowance to Directors	0·403	0·000403	0·099
Salaries	0·597	0·000597	0·145
Commission to Collectors	0·802	0·000802	0·196
Stationery, Printing, &c.	0·271	0·000271	0·067
Law and Parliamentary	0·195	0·000195	0·048
Sundries (Official Auditor)	0·023	0·000023	0·006
Total	2·291	0·002291	0·561
Total Maintenance and Management ..	10·863	0·010863	2·661
Total Gross Receipts	27·914	0·027914	6·839

it not at all impossible that the present Home Secretary might yet see his way to come to an arrangement with the water companies for the acquirement of their undertakings, even on the figures, large as they might seem, at which the late Mr. Smith had estimated their value. He trusted it would yet turn out that the supply of water by meter to the population of London would afford one way to those who were entrusted with the administration of the metropolis, not only of economising to a very large extent, but also of very materially lessening the rates now paid. He ventured to hand in a tabular statement, showing the average cost of the maintenance and management, and also the total gross receipts, of the eight London water companies during a period of nine years, reckoned both per million and per thousand gallons.

Mr. E. A. Cowper did not quite understand Mr. Hawksley's view, namely that, if meters were used universally for domestic service, the capital of companies would have to be increased 50 per cent.—certainly a rather startling amount. Neither did he quite understand Mr. Paget when he said that he had saved money by putting in a meter. He could understand the saving of money by having a constant supply and so doing without cisterns; but not how money could be saved by putting in a meter. He did not think that the quantity of water supplied was by any means a test of the exact cost to the water company. One half the capital of a water company was required for their reservoirs, engines, &c.; and if they supplied less water it would not save the company very much. Either domestic consumers were to pay less under the meter system, or they were to pay the same as now; if much less, then the water companies must suffer; if the same, then he did not see that there was very much benefit, except that the companies could then pump rather less water.

Mr. Hawksley said the average cost of water all over England was about 9*d.* per thousand gallons, including the interest on the capital invested; but the cost of lifting the water, even where coal was expensive, did not amount to more than a farthing per thousand

gallons for every hundred feet through which the water was lifted. Taking the case of London, and supposing the water to be lifted 300 ft., the cost of lifting would not be more than three farthings out of a cost to the consumer of about 7*d.*; the remainder of the 7*d.* resulting from the numerous other expenses additional to the cost of lifting, and from the interest on the enormous capital which the companies had to find in plant. And after all, the companies, taking into consideration the time they had been about it, were exceedingly badly remunerated. They did not get upon the whole capital invested, after seventy years of struggling, more than 6 or 7 per cent. on the average. He should like to know what tradesman or ironmaster would care to invest a large amount of capital, with the result that after struggling sixty or seventy years he would only get 6 or 7 per cent. interest upon his investment. That applied very materially to the question of the introduction of meters. Supposing the working classes, being supplied by meter, should reduce the quantity of water consumed by them to 6 or 7 gallons per head per day, or, as in one case in the paper, to $4\frac{3}{4}$ gallons, did they think that the existing rates would remunerate the water companies, who were now supplying water at 6*d.* to 1*s.* per thousand gallons at different towns in the kingdom—the average being 9*d.*? Why, with a diminished sale and an increased cost, they would have to raise their rates to 2*s.* 6*d.* Interest must be paid upon the capital expended, and the working expenses of the establishment must be paid; and the introduction of water meters, instead of being a benefit, might thus prove to be a great evil to the bulk of the population. It would not only have the effect of making every person reduce his consumption to a minimum, but it would also have the effect of raising the price, so that after he had reduced his quantity he would still be no better off than he was before. There was an immense amount of ignorance on this subject.

Mr. J. N. SHOOLBRED said that reference had been made to Mr. Deacon's Waste-water Meter; and, having had some experience of that meter in its early days, and especially as to its accuracy, he thought it might be not uninteresting to make a few remarks on this

subject. The principle of the Deacon meter was that the resistance to the flow should be always proportional to the motive power; thus ensuring equally accurate results at high and at low velocities. This was done, not by altering the resistance, but by making it truly constant, and by causing the opening through which the water passed to vary until the pressure due to the velocity balanced the constant resistance. The size of the opening was then the measure of the quantity of water passing.

The mechanism by which this result was obtained * consisted of a horizontal disc, balanced by a weight and suspended in a conical chamber, widening downwards and truncated at top, through which the water descended. The flow of the water depressed the disc until the annular space surrounding the disc was of such size that the pressure upon the disc due to the velocity was equal to the counterbalance weight. For each particular velocity in the main the disc would therefore find a particular position in the cone, and if that position were once determined for any particular volume of water passing, the same position would always indicate that volume and no other. The disc, through the agency of a wire, actuated a pen or pencil, which, by its vertical motion, recorded gallons per hour upon a sheet of paper wound upon a drum, which was caused by clockwork to make one entire revolution in 24 hours. This meter was therefore a *differentiating* meter; as distinguished from all other meters, including Mr. Tylor's, which were *integrating* meters.

Some years ago he (Mr. Shoolbred) had had an opportunity afforded him by Mr. Deacon of carrying out a series of tests in the Corporation yard at Liverpool, by causing the water, after passing through a waste-water meter, to enter a standard measuring tank, provided with a graduated gauge-tube for accurate measurement. An estimate was thus arrived at of the value of the waste-water meter as against the measured reservoir. He had given the results on a former occasion,† and they showed errors which compared very favourably with those quoted in the present discussion by Mr. Anderson.

* See Proceedings Institution of Civil Engineers, vol. xlii., p. 143.

† *Ibid.*, p. 204.

In the application of these waste-water meters to actual practice, the intended area of operations was divided into districts, containing each, on an average, a population of two to three thousand persons, or sometimes even as much as five thousand; and a meter was placed on the main supply to each district, so as to control it entirely. The diagrams depicted by it gave a complete and exact history of all that went on in that district; of the waste, as well as of the results derived from the curative measures adopted from time to time, in consequence of defects disclosed by means of the night inspections.

The annexed diagram-curves (Plate 7) were illustrative of the historical records of a district with a population of 4,740; the number of houses in it was 956, the average rental of each being below £30 per annum. Water-closets were connected with 95 per cent., and dry closets with only 5 per cent. of the premises. The upper diagram curve, drawn by the differentiating meter from noon of one day to noon of the following day, showed the condition of the district, when the night inspection of November 14–15, 1881, (marked in dotted lines) was made. The rate of supply indicated by the diagram at that time was 15·5 gallons per head per day. The amount of waste was exactly shown to have been 9·46 gallons. During the night inspection, the men's time was also checked by the meter. They commenced at 11.15 p.m. by closing the first wasting stop-cock, and so on; and terminated, after re-opening all the other stop-cocks in inverse order of the closing, by re-opening the first one at 3.30 a.m.

The diagram also showed, that the whole waste, except 100 gallons per hour, or 0·5 gallon per head per day, had been localised. The drop from 100 gallons to zero at 3.15 a.m. was caused by closing the main valve of the district, and it showed that valve to have been tight.

When water was being constantly drawn for use, the velocity in the mains was constantly varying, and minute by minute the disc changed its position in the conical tube. Each of the vertical lines on the diagram was the result of opening and closing a tap, or it might be two or more taps; and if the longitudinal scale were greater, then, instead of a single vertical line indicating the flow from a tap,

three lines would be shown: one rising nearly vertically to the point on the diagram representing the rate per hour to which the opening of the tap had raised the flow in the main, a short horizontal line showing the time during which the tap continued open, and a downward line indicating the reduction of velocity in the main when the tap was closed. As the diagram turned on the drum, and the evening hours were presented to the pencil, the number of draughts by taps was reduced, and a steady curved line was seen among the vertical lines. This was the normal flow from waste and ball cocks, and its downward curvature was caused by the gradual closing of ball cocks. By about midnight all the ball cocks in the district in question had closed, and there was left only a horizontal line, crossed here and there by a vertical line, when some sleepless person had drawn water from a tap. This horizontal line, so distinct from all other features of the diagram, indicated 1880 gallons per hour, or 9·46 gallons per head per day, wholly due to waste. Waste it was known to be, because from no other cause was perfectly steady and uniform flow obtained.

The repairs of leaks detected by the night inspection were completed before the lower diagram in Plate 7 was drawn, from noon Dec. 8 to noon Dec. 9, 1881. This diagram showed the total supply to be 9·28 gallons per head per day, and the waste 3·79 gallons. The saving was therefore about 40 per cent. upon the low original consumption of 15·50 gallons per head per day; and it was effected by one inspector and one labourer working one night, and one day inspector working three days. The result was the saving of 28,629 gallons of water per day. Under the system of house-to-house inspection it would have been necessary to inspect the whole 956 houses; and the result would have been comparatively insignificant.

Mr. E. B. Marten said, whatever might be the dislike to meters, he thought they would be forced upon water engineers by the power of public opinion, and therefore it became them to study how they could meet the requirements of the case. Great attention ought to be paid to what had been said by Mr. Hawksley, who had gone to the root of the matter, as to the effect generally of using meters. When

Parliament settled the rating clauses for waterworks, they seemed to have made a rough calculation that a water company ought to supply about 20 gallons per head per day, and ought to receive on the average 6*d*. per thousand gallons; but the company was not allowed to charge according to the quantity supplied, but rather according to the ability of the people to pay. The charge was treated not as a payment for value received, but as a tax, like the poor rate or any other tax, calculated according to rent paid, the rich having to pay for the poor. If therefore all the better class of houses were now allowed to have meters, they would pay so much less in proportion, that the average amount intended by Parliament would not be reached. The result would be, unless some remedy was devised and allowed by Parliament, that the companies would find their revenue reduced one half; which was very much equivalent to their capital being doubled, as Mr. Hawksley had put it. Mr. Paget's case confirmed this view. He had superseded what was the intention of Parliament in making the rating clauses, and had made a water company supply a consumer for domestic purposes by meter. If every one were to do the same, it would very much interfere with the company's property.

He had himself had considerable experience of what the present system of charge did in the way of leading to waste. Having had waterworks on lease, he knew what the value of the waste really was, as it came out of his own pocket. He was very keen at that time to detect where the waste was, and spent many a night in prowling about to find it; the result was he succeeded in more than one town in making the supply pipes so tight, that really they hardly passed anything at all during the small hours. At Wolverhampton he had had an opportunity of seeing the change from an intermittent to a constant supply. There was at first no reservoir, but they depended entirely upon pumping, and they were thus able to find out exactly what was used every hour; without giving all the figures, he remembered that between nine o'clock at night and six in the morning there was taken 14 per cent. of the total supply; and that was at a time when they were very nearly sure that there was no leakage.

When Mr. Tylor introduced his meter to him a few weeks back, he hailed it as a much easier means of finding out leakage than by the night-prowling referred to. He put one on to a district of 380 houses, and found that the average daily supply was 82 gallons per house, or 15 gallons per head. Having so light a consumption, he flattered himself that he should get a diagram like that shown for Bridgwater (Fig. 9, Plate 4); but unfortunately the diagram showed a great many notches during the night. Practically between 9 p.m. and 6 a.m., when there ought only to have been 14 per cent. of the water used, there was 30 per cent.; so that the result would no doubt be that he should find about 16 per cent. of waste during the night.* He thought they had perhaps overlooked one special object of Mr. Tylor in introducing the paper, which was to describe this particular recording automatic meter. He had himself found it an extremely handy instrument; the meter and apparatus could be very easily carried about, and by a few permanent arrangements, and making openings for attaching the meter on each side of the sluice-valves, one was able easily to test any district where there was suspicion of waste. He might suggest that, after what had been said about the use of meters in England and abroad, it would be well to obtain more information, if possible, both from continental towns and from towns in England supplied by meter, with regard to the effect of the meter system upon the revenue derived from domestic supply.†

Mr. W. Schönheyder said, if meters were to be used for household purposes, it was no doubt very requisite that they should register correctly for small quantities. The Tables I. and II. showed quantities registered by the smallest size—the ½-inch meter—varying from about 800 gallons per hour down to 20; and the percentages of variation from the direct measurement were very small, even for that large difference of flow. So far the meter appeared to be very satisfactory. He presumed however that with a lower rate

* This has since been confirmed by finding leakage through closets.

† Reports upon the results of the meter system, from the engineers of towns where it is in use, have been subsequently obtained, and will be found in the appendix, p. 96.

than 20 gallons per hour, or 12 gallons in Table II., the meters did not register very correctly. He had himself found, in carrying out experiments with a meter of somewhat similar construction, that with low quantities the percentage of variation became very great, and when the supply was still lower the meter fairly stopped. Mr. Paget had stated that in his opinion very few houses would use as little as 5 gallons per hour. He himself thought, on the contrary, that 5 gallons per hour was a very fair consumption; for if meters were used or abused in the way that Mr. Hawksley explained, by allowing the water to dribble during the whole twenty-four hours, then, taking the rate at 5 gallons an hour, they would still have 120 gallons to consume, which, at the rate of 15 gallons per person, would be sufficient for a house of eight people. But 5 gallons an hour was the least which any of the rotary meters tried by Mr. Anderson would register. In other words, the very best rotary meter would still allow water to pass without registration, in quantity sufficient to supply an ordinary London house containing eight people.

It had been stated by Mr. Rich that the results of trials had led to the adoption of the piston meter on the Continent, as the only class of meter that could properly be used with correctness for domestic supply. The only piston meters that were described in the paper were the Kennedy and the Frost. He understood that neither was very satisfactory; but possibly the Galasse meter which had been mentioned might fulfil all the conditions.

Mr. CHARLES HAWKSLEY, referring to the remarks just made by Mr. Schönheyder, observed that in Table VIII. he found that on certain days the meter was there shown to have registered only two gallons per diem; but as that water was not measured into a tank, it could not be taken as any proof that only two gallons really passed the meter on those days. Though the meter only registered two gallons, a much larger quantity might really have passed through. The low-pressure meter shown in Fig. 1, Plate 1, and referred to as Parkinson's meter, measured, he believed, the very smallest flows. He believed it was impossible, when that meter was in working order,

for any water whatever to pass through it without being recorded. That therefore was a perfect instrument for domestic supply, if it were wise to introduce meters at all for that purpose. The objection urged against that meter was that it would necessitate the servants of the water companies going to the top of the house when it was necessary to inspect the meter. He did not think however that this could be a very grave objection, seeing that they would make those inspections at reasonable hours, and that it was often necessary now to have plumbers, gasfitters, and other workmen in the upper parts of a house.

The use of water meters had been compared with that of gas meters; but in the case of gas meters it must be borne in mind that nearly four times as large a quantity was measured by each meter as would be measured by a water meter in use in a similar house. Therefore the cost of the gas meter only came to about one-fourth as much as it would do in the case of the water meter, compared with the quantity of the article supplied. Then again it should be borne in mind that water at 9*d*. per thousand gallons was just 2*d*. per ton; and that the water was raised, filtered, distributed, and carried to the tops of the houses for that very small charge. There were no other articles, he thought, which they could obtain at anything like that rate. Then in arranging the price, a good deal had been said about the cost to the consumer being diminished if the water was supplied by meter; but seeing that the cost of the works for the supply of water could not be diminished, it must necessarily follow that, in order to maintain the revenue required to pay interest on the capital outlay, the price to be paid must be increased, if the quantity used was decreased; and consequently the consumer would be left precisely where he was at present. The paper referred to the fact that in London the quantity supplied might be reduced, because the waste would be saved. That was true as regarded London; but in many of the provincial towns no such saving could be made, because the supply was already distributed in so efficient a manner, that there was very little waste to be saved. Then if the charge now made for water in the smaller houses were compared with the charge which it would be necessary

to make for the use of the meter, so as to cover the interest on first cost, the expense of visiting it and keeping it in order, and of taking it down—say once in three years—to be tested, and replacing it, it would be found that the meter rent alone would in many cases be almost as great as the present water rent; and therefore the cost to the consumer by meter would necessarily be increased instead of diminished. As far as the companies were concerned, the power of supplying by meter would be a great boon to them, because they would be relieved from the obligation to prevent waste. Each consumer would then be his own policeman, instead of having to be looked after by the officers of the company. But then all these consequences which he had endeavoured to lay before them would have to be met; and he did not think, when all was told, that the consumer would find he was benefited.

Mr. Paget had stated, as he understood, that, when he was about to have his house supplied in the regular way, the company had required such good fittings to be put in that he had found the cost would be very much greater than if he took the water by meter, and put in any fittings he pleased. But if the company which supplied Mr. Paget had a good set of regulations, the fittings they required were no better than ought to be employed, with a view to true economy; and, for his own part, if those fittings were not put in, he should be sorry to be a tenant of that house, because he should be afraid that one of these days, after a severe frost, he might find himself with a great deal more water than he bargained for.

As some reference had been made by Mr. Tylor to the waterworks at Bridgwater, he might mention that those works were constructed for the ultimate supply of a population of 20,000 people; and that the cost, including the application to Parliament, interest on capital during construction, and other charges, had been just about £40,000, or £2 per head of the population.

Mr. PAGET asked leave (in answer to Mr. Cowper's question) to explain one point, which clearly was not understood, namely how putting in a meter enabled the builder of a new house to save considerably in the cost of his fittings. The explanation was

perfectly simple. The water company, feeling that when the payment was by rate they (and not the householder) lost money by all waste, required the fittings to each closet, cistern, tap, &c., to be made in such a way as to form as far as possible a waste-preventer in itself; whereas, if a meter was used, they were quite content with this as the only waste-preventer, inasmuch as the cost of all waste then came on the householder, and not on the company. Thus one waste-preventer was substituted for a number according to the size of the house; and it was in that way that the money was saved. This would show that, though in old houses no immediate saving might result in the fittings from the use of meters, in all houses built or fitted for water supply after the use of meters was allowed there would be a large saving.

There was one other point on which he thought a little misapprehension might have arisen. The amount of water which Mr. Anderson gave as possible to pass through a meter without registering was approximately 5 gallons per hour; and that had been spoken of as being a serious loss to the water companies. But if it were calculated, it would be found that it would require patient, persevering, cleverly contrived, and continuously carried on robbery for an uninterrupted period of more than a week to draw at that rate 1,000 gallons without registration, and that 1,000 gallons would probably cost about 6*d.* Therefore he did not think the water companies would be large losers by that means.

Mr. Tylor, in reply, said with regard to Mr. Anderson's observations he had had no opportunity of making experiments with the Galasse piston meter. There had been so many new meters introduced during the last few years that, until a considerable number had been sold and used for some years, a foreign meter did not come very prominently forward in this country.

In answer to Mr. Hawksley, to whose great experience in all matters connected with water companies he naturally must bow, he thought that, notwithstanding all his knowledge on this subject, his argument in reference to meters was perhaps a little stronger than it need have been. He had referred to the private consumer abroad as

being very acute and careful to take every possible advantage of the water meter; but although the amount of water consumed per head per day, in the principal towns in Germany and France with which he was acquainted, was very much less than in England, varying in those towns from 8 to 15 gallons, yet nearly all those towns of late years had elected to be supplied by a rotary meter of one kind or another. In many cases they had discarded the piston in favour of the rotary meter. The first three trials appended to the paper were the actual trials carried out by the Frankfort water companies, during a competition which lasted upwards of two years, in order to decide on the best meters to be adopted for use in that town. The minimum flow in those trials, at which fairly accurate registration was obtained, represented no doubt a large quantity in the twenty-four hours; but still those trials ended in the adoption of rotary meters as the best for domestic purposes; and the use of such meters was continually increasing to the present day. He thought this fact ought to influence to some extent their proceedings in this country.

With reference to the question of constant and intermittent supply, raised by Mr. Hawksley, of course with a constant supply there was the possibility of the ball valve in the cistern leaking or being tied up, and a small flow thus running continuously. On the Continent as a rule no cisterns were used: which he ventured to think was a great advantage to consumers, who naturally desired fresh cool water. But very frequently the constant supply given by English water companies was really only an intermittent supply; the cistern emptied itself partially during the day, and was suddenly filled up at the time when the water was turned on by the company, or when the pressure increased by the absence of a great demand through the mains. In the trials given in the paper he had chosen an intermittent supply of that kind, Table VIII., so that there could be no question of the meter registering exactly, inasmuch as the whole day's water supply passed into the cistern in the course of half-an-hour or an hour.

With reference to the question of economy, he must again refer to the experience on the Continent; for the people there would

certainly not pay more for their water than they could help. The cost of the meter was paid by the company in some cases, and by the consumer in others. In England, unfortunately, there were hardly any cases of meter supply for domestic purposes. He believed that Great Malvern and Newport (Isle of Wight) were the only cases; and even there the number of meters fixed was so small as hardly to afford a good criterion. At Newport the number was 136 Tylor meters and 3 Siemens meters. At Great Malvern meters were fixed on most of the houses, and the result, as the town surveyor stated, was to give a consumption of about 10 gallons per head per day.

As to the actual expense of meters, if it was admitted that meter supply was an advantage in checking unnecessary waste in towns, and thereby adding to the efficiency of the service, he did not see that it would be unreasonable to ask people in houses of a good size—he did not say in smaller ones—to spend £3 upon them; seeing that the Commission of 1872 had recommended, on behalf of the waterworks and in their interest, a house expenditure which amounted to a much larger sum, estimated at from £10 to £30 per house. He thought many of the inhabitants would cheerfully pay something to have water meters, and he believed that eventually it would be to the interest both of the water companies and of the consumers. If it were not so, some scale would of course have to be arranged which would make it fair to the water companies.

In regard to the inspection of waste, he knew that the towns of which Mr. Hawksley had charge were amongst those where the service was most effective, and where the waste had been most reduced; but his own argument was that by the use of some kind of apparatus to examine the mains automatically a great deal of inspection might be saved. Amongst other things one great advantage was gained; the inspectors had not to be constantly going into the houses of the inhabitants. There was another difficulty which Mr. Hawksley himself had referred to, and which arose only with the use of low-pressure meters: namely that they must be placed at the top of the house. The inspectors had then to enter the houses to read or examine the meters, and no water could be drawn except

through the cistern; and any system that would enable the companies to detect waste from the outside, without internal examination of the fittings, was clearly an advantage. The apparatus introduced by Mr. Deacon, and Messrs. Tylor's apparatus for the same purpose, were merely an assistance to the inspectors, pointing out during the hours of the night what took place in the mains, and allowing the subdivision of a large district into smaller districts, which could be more easily watched. The clock could be readily removed at any time, as suggested by Mr. Rich; and the meter was an ordinary meter, useful for other purposes besides district examination. The meter could be left permanently in the ground, to show whether the consumption decreased after inspection, and the clock could be replaced upon it whenever a diagram was required; or the meter could be taken away again, and used for other purposes.

In reference to Mr. Schönheyder's remarks as to piston meters and inferential meters, he need only repeat that there were a very large number of inferential meters still being fixed on the Continent, and a continual increase in the number fixed for domestic service. As to the opinion that the minimum quantity shown in the trials was still too large for domestic supply, he thought it was now agreed on all sides that for sanitary reasons some sort of minimum charge ought to be fixed, if meters were used. It ought not to be the interest of the consumer to economise below a certain limit. If a minimum limit of 15 gallons per head were fixed, this would be about equal to 180 gallons per day for a good sized house, which would be above the minimum registration of his meter, as shown by Mr. Anderson. A minimum charge existed on the Continent in a very few cases to his knowledge.

Mr. Charles Hawksley had compared gas and water meters; but he did not himself think that they could make any very exact comparison between the two. Probably the fight, at the time when gas meters were introduced, took a somewhat similar course to the present contest as to water meters. It was a question of disturbing existing arrangements; and he supposed that some means were found of meeting both sides. A gas meter now cost a small sum; and it was probable that water meters, if they were introduced universally, would not cost much more than gas meters.

APPENDIX TO DISCUSSION.

(Information received in answer to enquiries.)

At Newport Water Works, Isle of Wight, the manager, Mr. James Cogger, states that there are only 136 Tylor meters and 3 Siemens meters in use, 70 of them for supply to private houses rented at from £12 to £70 a year. The meter rent is 15 per cent. per annum on the cost of the meter. The minimum charge for the water supplied is 10*s.* a year. The rate per thousand gallons is 1*s.* 6*d.* up to 30,000 gallons a year; 1*s.* 3*d.* from 30,000 to 60,000; 1*s.* from 60,000 to 90,000; and 8*d.* for 100,000 gallons or upwards per year. No difficulty has been experienced with the meters, except during the severe winter of 1880–81, when eight or ten had to be taken out for repairs. A great loss is sustained by the corporation in supplying private houses by meter; and they are trying to do away with the meters in consequence. Some houses, which used to pay about 40*s.* a year for water on a rate of 9*d.* per £ on the house rent, are now paying sometimes not more than 10*s.* a year by meter. The pumping amounts to only 12 gallons per head per day, of which about half is believed to be wasted. The lower service furnishes a constant supply, and the higher is on from 7 a.m. till 5.30 p.m.

At Great Malvern Water Works, the town surveyor, Mr. John E. Palmer, states that the meter system was adopted about ten years ago, for the sole purpose of preventing waste, which up to that time had been very considerable. The charge for the water was settled by a provisional order at the uniform rate of 1*s.* per thousand gallons. Having had ample opportunities of testing the value of the meter system during the past seven years, and especially in the summer season when the supply is reduced to a minimum, he is fully convinced that such a system can be successfully adopted in any town. The registered consumption at several of the good houses has often been observed, and has been found not to exceed 10 gallons per head per day; while in its sanitary condition the town is considered to rank second to none.

At Hereford Water Works, the late city surveyor, Mr. George Cole, has stated that there are 160 meters in use, which indicate a consumption not exceeding 10 gallons per head per day, whilst the average consumption over all the city amounts to 40 gallons, showing a waste of 30 gallons per head per day. This is entirely wasted, doing no good in a sanitary way, for it only dribbles through $\frac{3}{4}$-in. taps or closet valves, and does not flush the 6-inch pipe-drains between the houses and the main sewers. The principal thing wanting to remedy this waste is that the user should be made responsible for the waste. There are two water-tap inspectors; and a waste-water meter has been fixed in one of the districts in the city, but has had no effect in stopping the waste. The fairest plan to the consumer would be to charge by meter at a rate of from 1*s.* to 2*s.* per thousand gallons. The present mode of charging by rental is altogether inequitable, careful consumers having to pay for the careless and extravagant; and some consumers in Hereford are known to be paying as high as 5*s.* per thousand gallons for the water they use, while the very next house may not be paying 2*d.* per thousand gallons. The charge by meter would not bear hard on the poor, because for all houses of less rent than £10 a year the water rate is paid by the landlord, who is the proper person to look after the water consumption, and to see that proper use is made of the water. On first putting in a water meter to a house, it is often difficult to convince the occupants of the extravagant waste that has been going on; but as soon as they find the waste has to be paid for, they have all the fittings put in order, and proper care taken to avoid wasting the water. A reduction of 75 per cent. in the consumption has been observed in some houses, after the first month's use of a meter, and the houses are still kept quite as clean as before: proving clearly the useless waste that had occurred previously. The water consumption in a house, in the absence of the head of the family, has been known to rise from 8000 gallons per month to 150,000. The register of the meters is taken every month, and a copy of it is furnished to the consumers, so that they may check any waste that has been going on at their premises. For the flushing of drains a single bucketful of water thrown down suddenly will do more good than a dribble that

produces a very serious waste. Flush-wells are provided in Hereford at the ends of all the main sewers, and the sewers are well flushed out every week, whereby they are kept as clean now as they were when first laid down twenty-six years ago.

At Northampton Water Works, the secretary, Mr. Henry Armitt, states that the charge by meter is a minimum of 7*s*. 6*d*. per quarter, exclusive of rent of meter, and 1*s*. per thousand gallons for all water consumption above 7,500 gallons per quarter. The meter rent ranged from 1*s*. 10*d*. per quarter for a ½-in. meter, to 11*s*. 9*d*. for a 4-in. meter. The meters supplied by Messrs. Guest and Chrimes are found to answer admirably.

At the Reading Water Works, the engineer, Mr. A. T. Walker, states that in the Bath Road district now under inspection (*see* Table XIII., p. 63) the inspection is being carried out by means of two 3-in. Tylor meters, two 4-in., and one 5-in., with two sets of automatic clock apparatus and diagram drums, which can be removed and affixed to any meter. The cost of fixing a 3-in. meter direct in the main would be £2 6*s*., including a cover to protect it. If a by-pass and two sluice-valves were added, these would bring the cost up to £8 15*s*. He recommends that all water companies should employ either a main meter to indicate correctly the total actual consumption, or a number of district meters. Their adoption would result in an immense saving of pumping power, and would facilitate the nightly search for causes of waste. As examples of the results arising from the use of meters, the following cases are cited from among the consumers at Reading. A dyer had previously paid by agreement £2 per annum; but on applying the meter the charge of 1*s*. 3*d*. per thousand gallons raised the payment to £6 2*s*. 6*d*. per annum. Another dyer, who had previously paid by agreement 15*s*. per annum, now pays by meter at 1*s*. per thousand gallons £10 16*s*. per annum. An institution, previously paying by agreement £25 per annum, now pays by meter at 6*d*. per thousand gallons £71 13*s*. 4*d*. per annum. A bath house, formerly paying by agreement 8*s*., now pays by meter at 6*d*. per thousand gallons £6.

A tradesman, who had paid by agreement 30*s.*, is now paying by meter at 1*s.* per thousand gallons £10 16*s.* A hydraulic engine blowing an organ was charged by agreement £5 per annum; by meter at 6*d.* per thousand gallons it is now paying £20, and has in one year paid as much as £60. On the other hand, a dwelling house, with bath, three closets, and large garden with fountain, would have had to pay by rate as much as £6 6*s.* 8*d.* a year, but by meter paid only £1 10*s.* a year.

ON THE BAZIN SYSTEM OF DREDGING.

BY MR. A. A. LANGLEY, OF LONDON.

The following paper contains a brief description of the construction and working of a Dredger, designed on the system invented by M. Bazin, the well-known hydraulic engineer, and used by the author for the past three years in dredging sand and other material in Lowestoft Harbour.

Construction.—The dredger is represented in its general features in Figs. 1 and 3, Plates 8 and 9. The total length of the hull is 60 ft., with 20 ft. beam. In the after part of the hold is placed a horizontal boiler A, Fig. 1, which supplies steam to a pair of inverted vertical engines B, Fig. 3. These engines drive, through belts and overhead pulleys, a centrifugal pump C. The suction pipe D of this pump passes through the side of the dredger, and then forms an elbow bent downwards at an angle of 45°. To this elbow is attached a flexible pipe E, 12 in. diameter and 25 ft. long, made of india-rubber, with a coil of iron wire inside to help it to keep its shape. At the lower end of this pipe is an elbow-shaped copper nozzle which rests on the bottom, and is fitted with a grating to prevent stones getting into the pump, and stopping the work.

The flexible tube E is supported by chains that pass over the head of a derrick F, mounted at the stern of the dredger, and then round the barrel of a steam winch G, Fig. 1. By this means the depth of the nozzle is altered, as required to suit the depth of water. A man stands at the winch, and lifts or lowers the pipe as is required, judging by the character of the discharge from the pump. If the liquid

discharged is very dark and thick, he knows that the nozzle is too deep in the sand or gravel, and he therefore raises the pipe; but when the discharge is of a light colour, he lowers the pipe, since the proportion of water to sand or gravel is thus seen to be too great. The best proportion of water to sand, according to actual experience, is 5 to 1. When loose sand is the only material to be dealt with, it can be easily sucked up, even if the nozzle is deeply buried; but at other times stones interfere with the work, and the man in charge of the flexible tube has to be very careful as to the depth to which the nozzle may be buried in the sand.

The action of the apparatus will be at once understood. The pump, being worked by the engine, draws up the water and sand from the bottom through the flexible pipe E, and discharges it into the wooden trough H; from thence it falls into hopper barges, Fig. 3, placed at either side as convenient. So powerful is the action that at Lowestoft, before the grating was fixed to the nozzle, large stones and iron bucket-pins, in some cases over 3 lbs. in weight, were sucked up and passed through the pump.

The pump itself is shown, in longitudinal and horizontal section, in Figs. 4 and 5, Plate 9. The fan is 2 ft. diameter, and has only two blades. Originally it had four blades, but on one of these getting accidentally broken, the action was found to be improved, and eventually it was found to work best with the two only. The faces of the blades, where they come in contact with the sand, are covered with flaps of india-rubber. Small doors are provided at the sides of the pump, for cleaning it out, extracting stones, &c. The fan makes 350 revolutions per minute, and at that speed is capable of raising 400 tons of sand, gravel, and stones per hour, but the average in actual work may be taken at 200 tons per hour. This is with a 10 HP. engine, and working in a depth of water varying from 7 to 25 ft.

Applications.—The great advantage of this dredger is its capability of working in disturbed water, where the frames of a bucket-dredger would be injured by the rise and fall of the vessel. Thus at Lowestoft bucket-dredgers are used inside the harbour, and the Bazin dredger at the entrance, where there is sand and gravel, and where the water is more disturbed. The dredger does not succeed

very well in soft silt, because it runs over the sides of the hopper barges without settling. Nor is it good for dredging solid clay, which is difficult to suck up. It gives however excellent results with sand and gravel, and for this work is much superior to the bucket dredger.

Experience in Working.—In May 1876 the author went to Angers, to see a dredger on the Bazin system, which was working there on the river Loire. It was roughly fixed in a barge, and was excavating sand for the foundations of a large bridge over the river—a work which it seemed to perform in a very satisfactory manner.

In consequence of the author's report, a contract was entered into by the Great Eastern Railway Company with Messrs. Charles Ball and Co. to supply a dredger of the same kind for Lowestoft, the terms being that it was to dredge 100 tons per hour before it was accepted. Between September 1877 and July 1878 many attempts were made to get this dredger to work satisfactorily, but all without success; and the contractors became so disheartened with their failures that they were disposed to abandon the contract altogether. The author was very reluctant that this should take place, as he felt persuaded that it only required perseverance to make the arrangement a success; and this has been justified by the result. One of the chief alterations which produced the final success was made by Mr. Charles Ball, managing director to the contractors, and consisted in the introduction of india-rubber flaps attached to the blades of the fan. This enabled stones, gravel, &c. to be dredged without damage to the pump. Before this, although cast iron, wrought iron, and steel were all tried for the blades, it was found that in a very short time both the blades and cheeks became so cut and abraded by the gravel passing between them as to be unfit for use: but the soft india-rubber yields to the cutting action, and thus escapes much injury itself, while it prevents all injury to the cheeks. The india-rubber used is of a tough description, $\frac{1}{2}$ in. thick, and is cut into pieces 5 in. by 10 in. Slotted holes are cut in each piece, and bolts passing through these hold it down to the blade. When the outer edge of a piece is much worn, it can be pared off, and the piece

moved outwards on the blade by shifting the holes, thus exposing a fresh edge. This operation is performed every fourteen days at a cost of only about four shillings. It is this feature which gives the Bazin dredger its special capability of dredging with economy in rough stony ground. Sand pumps were used for dredging in the construction of the Suez and Amsterdam canals; but the author believes the dredger now described to be the only one that will effectively dredge gravel or large stones.

Apart from the wear of the fan, the chief difficulties which were experienced were as follows :—

1st. The difficulty in keeping the dredged material from flowing over the sides of the barges. When dredging in alluvial silt, it took more than an hour to dredge about half a barge load, or 30 tons; since, owing to the disturbed state of the water, the material would not settle to the bottom of the barge, but ran over the sides. Several methods were adopted to avoid this, such as dividing off the barge by partitions into settling chambers, directing the shoot into different parts of the barge at stated times, &c., but all to no avail. Finally it was concluded that the dredger was not suited for this light material, unless it could be thrown on to a large area, as over a bank into a field or vacant space, where sufficient area could be allowed for settling. Such cases would often occur in the dredging of rivers; but for harbour work the dredger is only available for shingle and sand.

2nd. The choking of the nozzle and suction pipe, owing to pieces of canvas, old bags, timber, baskets, &c., being drawn in with the sand. This was provided against by fixing iron bars across the face of the nozzle, thus forming a kind of gridiron and preventing the pipe from getting choked. Although these obstructions stick on the gridiron, yet, when the pump is stopped for a moment, they drop off into the water.

3rd. The fact of having to force the sand and shingle, after being pumped, along a horizontal 12-in. pipe which led along the top of the dredger into the shoots. If the sand came too fast, and not sufficiently mixed with water, it was a case of forcing a solid block of sand through the pipe, which thus became choked and stopped the engine. This was remedied by replacing the 12-in. pipe by an open

wooden trough 16 in. square, as shown in Fig. 1, Plate 8, thus giving twice the area, and preventing the possibility of choking.

There were several minor difficulties experienced through the imperfections of the machinery. For example, the smoke-box of the boiler was not sufficiently large, and frequently got red hot, and the boiler also primed considerably. These were remedied in the best way available, as they arose.

Cost of Working.—The vessel or barge for carrying the machinery and pump cost £600, and the contract price of the machinery and pump was £1,200. But before the dredger was taken over by the Company the alterations before enumerated had cost about £300, bringing the total for barge and dredger up to £2,100. In building a second dredger this might of course be greatly reduced. The cost of repairs for one month's working has been only £5.

The contractor receives for labour alone $2\frac{1}{8}d.$ per ton, being at the rate of about $1\frac{3}{4}d.$ for the dredging and $\frac{3}{8}d.$ for taking to sea (a lead of two miles), all materials being supplied to him. The consumption of coal is at the rate of about 1 ton for 1000 tons of sand dredged. At Lowestoft harbour the total amount of dredging has been about 200,000 tons yearly, but this is now much reduced in consequence of the pier extension recently constructed by the Author, which now prevents the sand and shingle from the sea blocking the mouth of the harbour. The services of the Bazin dredger are in consequence not so necessary.

The figures for cost, with this dredger, are as follows :—

Cost of dredger, say	£2000
Nominal horse-power	HP. 10
Depth at which it excavates	ft. 25
Quantity excavated, per annum	tons 200,000
Labour for dredging, lead (2 miles), and discharging, per ton	2·125*d.*
Coal and other stores, say per ton	0·375*d.*
Repairs (total £60)	0·072*d.*
Total working cost per ton	2·572*d.*
Add 10 per cent. interest on capital	240*d.*
Total cost per ton, including interest on capital	2·812*d.*

The total repairs to the steam-tug, hopper barges, and dredger, have averaged about 2*d*. per ton.

Since 1 ton of the liquid dredged will very approximately occupy 1 cubic yard, these figures may be at once compared with those given by Mr. Buckley, Proceedings 1879, p. 552. It will be seen that the cost is far below that given for bucket-dredgers, and will compare favourably even with that given for Mr. Fouracres' dredgers, when the greater lead, and the high cost of labour in England as compared with Bengal, are taken into account.

Discussion on the Bazin Dredger.

Mr. Langley wished to add that several attempts had been made to put the engine directly on to the fan of the pump, but without success. The present arrangement was to drive from a belt, and that acted as a sort of safety-valve. Directly the pump showed a tendency to choke, instead of the machinery breaking (as it would do if the pump were attached direct to the engine), the belt slipped; and therefore he thought this was the best arrangement that could be adopted.

He had used the dredger very successfully to pump water. A short time ago he had had to reconstruct a lock at Mutford, near Lowestoft; and having made a cofferdam at each end of the lock, he put the nozzle of the suction pipe through the dam, and used the pump to suck out the water from the lock. Some of the men put a net in front of the delivery pipe, and managed to secure nearly a cartload of fish of one kind or other; amongst others, a crab about seven inches across the back, and also many eels.

He had frequently been asked whether the Bazin dredger compared favourably with the bucket dredger. That was very much like asking a carpenter which was the most useful tool he had in his basket. He would naturally ask, "What do you want it for?" It was the same with the dredger. To dredge clay, it was no use putting in a suction pump, for it would not suck it up; if it was mud, it would be of no use, because the mud would flow over the sides of the barge; but for gravel or sand he believed there was no better dredger when it was properly worked; it would do very much more work, and at a very much less rate, than the ordinary form. If any gentleman desired to ask him any questions on the subject, he should be happy to afford any information in his power, either there or afterwards at his office.

Mr. C. P. Skerrett, having been in charge of the dredging for the Great Eastern Railway both at Lowestoft and at Harwich for five years, hoped to be allowed to make a few remarks on the interesting paper of Mr. Langley. For many years dredging had been carried on at Lowestoft by means of three large bucket-dredgers; but it was with the greatest difficulty that they were able to overcome the accumulation of sand and shingle, which the north and north-easterly winds brought in in large quantities between the pier heads. The Bazin dredger however came to their assistance; and with that, and the extension of one of the piers seawards, they had been able to overcome the difficulty.

The details of the dredger had been gone into minutely in the paper, but he had made a few further notes on that subject. The boiler was of the usual multitubular kind, 11 ft. long and 4 ft. in diameter, with a working pressure of 60 or 70 lbs., and consuming about 5 tons of coal per week, when working on an average about eight hours a day. The engines consisted of two inverted cylinders, 9 in. diameter and 10 in. stroke, making about 120 revolutions per minute. The higher velocity of the pump was obtained by means of a leather belt on a counter-shaft. As mentioned by the author, the engines were frequently pulled up in the first trials in consequence of a large block of sand forming in the vertical pipe above the pump.

That they had remedied by doing away with the horizontal portion of the 12-in. delivery pipe, and substituting the open wooden trough H, Fig. 1, Plate 8, about 16 in. square. The flexible pipe which they were now using at Lowestoft was not quite so long as mentioned in the paper. Although the suction pipe was 25 ft. long altogether, it was now divided into two portions, one of galvanised iron 12-in. pipe, 15 ft. long, and only the remaining portion, about 10 ft., of india-rubber flexible pipe. That was owing to the great difficulty experienced in getting a good flexible india-rubber pipe. Owing to the knocking against the soil at the bottom, against sand and stones, and against the dredger, the flexible pipe was liable to be broken; they therefore used it as short as possible, of course long enough to allow working in different depths of water.

The hopper barges that had been mentioned had a capacity of about 65 tons each. They were square-nosed, and cost from £180 to £200 each. They were towed out to sea by a tug, and to empty them a trigger was knocked upwards, to which was attached the chain holding up the doors in the bottom. A short time ago one of their men, in knocking up the trigger, slipped, and went with the mud through the bottom of the barge. He was however none the worse for his experience.

With regard to the fan, they at first had a four-bladed fan, but, as the paper said, one of the blades got broken, and then they had a new fan made of two blades. They were however now using one with three blades, and equally good results were obtained with it. Dredging in solid clay certainly had not succeeded at Lowestoft; they could dredge mud, but solid clay would not come up. An arrangement existed by means of which a species of plough was set to work in advance of the suction pipe, to break up the soil so that it could be dredged. If the spoil could be discharged from the dredger over a bank or a dam, or upon a large surface, so as to give time to settle, he had no doubt the dredger would be equally efficient with broken clay or mud. Besides the blades and cheeks being worn at first, as the paper had stated, by the grinding action of the sand and shingle, they also found it so with the spindle of the pump; and they had to renew it four or five times, which was rather costly, and

occasioned considerable loss of time. They managed to avoid this difficulty by using conical brass bushes, which could be moved inwards on the spindle as required, and which were very easily renewed. The india-rubber flaps which they bolted on to the blades of the fan were at first made each in one piece, but they were now cut longitudinally down the centre, and fixed in two portions; so that, when the outer edges were worn, instead of having to renew the entire piece, they merely moved the two portions laterally outwards on the blade and then screwed them down again, thus leaving a fresh edge projecting beyond the edge of the blade.

With regard to the cost of the barge which contained the pumping machinery, it was put down as £600; but that, he thought, was scarcely a fair criterion, as it was the first of the kind made at Lowestoft, and he believed the second of the kind ever made in England. With their present experience no doubt the cost could be reduced to one half. The paper stated that 200,000 tons of sand had been dredged at Lowestoft. That was not by the Bazin machine exclusively, but by two bucket dredgers and one Bazin dredger. In one case they had used the dredger with the greatest advantage. The Lowestoft Water and Gas Company, under the supervision of Mr. Hawksley, were laying some gas and water pipes across the harbour, and for that purpose they had to cut out rectangular pockets, 9 ft. by 5 ft., from the sides of the quay wall. These had to be dredged in order to admit the vertical portions of the gas and water pipes. In such a case the bucket dredger would have been useless; but they directed the nozzle of the suction pipe of the Bazin dredger into the pocket itself, and in a very short time took out the necessary quantity of sand. Mr. Langley had mentioned the case of a lock gate at Oulton Broad near Mutford. There they passed the suction pipe of the dredger through the cofferdam, which they had to drive on either side, and then vertically downwards almost to the bottom of the lock. The dredger acted as a first-rate centrifugal pump, pumping out water at the rate of 2,000 gallons a minute. In that case it had a vertical suction of about 14 ft.; whereas when working as a dredger it had no suction, because the centrifugal pump itself was under the water-level outside. He at first feared that

it would not work well with the 14 ft. suction; but by fixing a foot-valve on the bottom of the suction pipe, and so always keeping the suction pipe filled, it answered very well indeed.

Mr. CHARLES BALL said his experience with this form of dredger had been extensive, there being twenty or thirty of that class at work in different parts of the world. He was much obliged to Mr. Langley for the kind mention of his name in connection with the invention which had made the pumping dredger practicable; and he would take the liberty of explaining the difference which existed between the Bazin dredger, as he had supplied it at first to the Great Eastern Railway, and the Ball dredger which they were now using. M. Bazin's idea was that by placing what he called a rotary elevator of any kind at a certain distance below the surface of the water, the hydraulic pressure outside the vessel would produce an immense inrush of water, which he called a gratuitous advantage; but he (Mr. Ball) supposed that if the water rushed into the boat it still had to be pumped out, and therefore the inflow would not be gratuitous, the expenditure of mechanical power being about the same when employing the centrifugal pump for forcing as for suction. That was the form of dredger he first sent to Lowestoft; and one of the difficulties of the system was that, in order to obtain any head of water worth the name, it was necessary to sink the pump far below the surface; it therefore required specially constructed dredging plant, drawing much water. In the case of Lowestoft, after scheming a great deal, with the assistance of the engineers of the railway, he managed to get the centre of the pump about 2 ft. below the level of the water. The results were not very satisfactory. In twelve months they dredged 738 tons, they spent £340, and they replaced the pump, or at least the inner parts of the pump, two or three times. When the face of the fan blades was made of india-rubber, the difficulty of wear disappeared. The practice which he had acquired then and since had proved that the position of the pump was absolutely of no importance whatever; but that what was required was a special pump, capable of passing thousands of tons of material per day without wearing at all. It was particularly inconvenient to put the pump

below the surface of the water for several reasons; first, because it necessitated special craft, which generally had to be built for the purpose, and secondly, because it necessitated an opening in the side of the boat, communicating with the interior. Then, if they had to open the pump, the water would rush into the boat and swamp it immediately. It was therefore necessary to interpose a sluice-valve between the pump and the water. But the sluice-valve was very difficult to manage, and when pumping stones or pieces of metal it often would not shut. Anyhow, he had found it possible to place the pump above the water level; in fact his usual practice now was to place the pump 3 or 4 ft. above, and under those conditions he required no special craft. He could take a fishing smack, and as long as it would carry a boiler and engine his pump could be put upon the top, the whole thing weighing 12 tons, for a dredger that could raise 100 tons of material an hour.

In placing the pump above the surface of the water, he met at once with a difficulty, which was that the centrifugal pump would not start, as they all knew, unless it was filled beforehand; and being above the level of the water, it was impossible to fill it unless there was a foot-valve. The same objection which applied to a sluice-valve between the water and the pump applied equally to the foot-valve, which would never work when sucking stones, gravel, &c. But he had succeeded in arranging so that the pump, though placed 3 or 4 ft. above the surface of the water, could be filled almost instantly, and when once filled it would remain full for weeks, and would start whenever required, without there being a foot-valve or any impediment to the passage of materials. With the pump first tried at Lowestoft, the delivery pipe was vertical, and there was another difficulty: whenever the pump stopped, a whole column of gravel fell back into it, the result being that, when the engine started again, the strap slipped, and it could not start. At Lowestoft this was altered by fitting a horizontal length of delivery pipe next the pump, and then turning it upwards further on. If the gravel then settled it obstructed the pipe a little, but it did not reach the vital part of the pump. To get the pump started without filling he had gone further in the same direction, and had bent the pipe first down and then up

again. If the bottom of this bend was below the external water-level, then there were evidently two columns acting against one another. If the column in the bend was the longest, naturally the air could not come in, and the pump could be stopped for any time, and would always be ready. In order to start the pump he used a simple ejector, putting for the moment a flap of india-rubber on the end of the delivery pipe until the vacuum was produced. As soon as the pump was partially filled by the action of the ejector, the machinery was started. It took about 30 to 45 seconds to start the pump; the only point was to make the ejector sufficiently large.

One of the great advantages of this pump was its power not only of dredging, but of conveying materials through long pipes. In one case at Langenbrugge in Holland the spoil was carried 1,200 yards through pipes, thereby doing away entirely with all loading into barges and a great amount of labour. But to do that it was necessary first to avoid choking. Now the remedy which had been adopted at Lowestoft would not apply to that case, because, if it was desired to force material a great distance, it was impossible to use, as at Lowestoft, an open channel. It was also necessary to make sure that too much material was not taken at one time. The arrangement that was employed very successfully was to use a simple vacuum gauge on the suction pipe, brought under the eye of the man who was in charge of the nozzle ; because, though one could see the nature of the material and the quantity which was coming by looking at the delivery, that was no longer possible when the delivery was 400 yards away. Suppose that the pump had a tendency to choke, then the vacuum inside the pipe would increase; therefore by placing a common vacuum gauge on the pipe, and giving it a sufficiently large dial, the man could see the hand moving towards the vacuum, and would know that he ought to lift the nozzle, so as to suck more water in with the sand. On one occasion, when dredging ballast for the Orleans Railway on the River Loire, he had the misfortune of seeing the whole of the delivery pipes disappear under water. The pump had taken too much sand ; the men were not quick enough in relieving it, and the delivery pipes completely filled with sand; the buoyancy which they received from some empty barrels was not sufficient to keep them

afloat, and they sank, and had all to be unbolted under 4 ft. of water. He had afterwards thought of making the vacuum itself remedy the evil automatically, and had done so with success, by means of the contrivance shown in Fig. 2, Plate 8. Just above the mouth of the nozzle a number of large openings were made all the way round, and then for simplicity these were covered with a ring of india-rubber having a slit opposite each of the openings. If the thickness of the india-rubber was properly proportioned, the result was that, as soon as the nozzle began to choke, sufficient vacuum was produced to make the slits open inwards, and a stream of water then entered, and prevented any further choking.

Another very great difficulty was in dredging foul ground, *i.e.* ground filled with various obstructions, as inside harbours, where sails and straw and things of that kind had accumulated. The grating of the nozzle then got completely filled up, and nothing could enter it. The remedy was to take up the nozzle and clear it; but in so doing the engine had to be stopped, and it took some few minutes to pull away the obstructions. After trying a great many devices on a dredger at Smyrna, dredging the harbour for Messrs. Dussaud, he hit upon a very simple expedient. The iron suction pipe was made to end in a fork, and to each of the two branches was applied a separate flexible pipe and nozzle, lifted and lowered by two separate ropes, running on the same barrel of the steam winch but on opposite sides; at the junction of the branches was placed a valve, which could be moved so as to shut off one side or the other, according to the will of the dredger foreman. As soon as one nozzle began to get foul, he shifted the valve so as to draw from the other, while the first was lifted up and cleaned; and by the time the second was foul the other was clean. The result was that, although the obstructions were continual, yet the work of the dredger was also continual, with only the additional expense of the wages of one man, a labourer occupied with an iron hook in cleaning the nozzles. He had saved thereby 35 to 40 per cent. in the working of the dredger.

As to the price of these dredgers, of course it varied according to what they were intended to do. A dredger of that class, not floating but mounted on wheels, to cut ditches through salt pans in the south

of France, near Marseilles, cost £480. When tested it dredged 750 cubic metres, or 1,500 tons, in two days. He had also worked on the Loire, where there was a peculiar difficulty from the exceeding shallowness of the river, and the occasional sudden fall of the water. Contractors had to be exceedingly careful with their dredgers, but even then they were sometimes caught and stranded high and dry on the banks of the river, where they remained four or five weeks or more until a freshet came and took them away; and that was of course very expensive to the contractors. But the simplicity of the Ball arrangement was such that he was able to use a local boat made to carry cargo, exceedingly long and wide, and drawing only 2 ft. In the case of Angers, with the engine fixed and ready to work, the boat only drew 1 ft. 4 in.; and that engine, with only a 9-in. suction pipe, raised 195 tons, on the average, per hour.

Mr. T. R. CRAMPTON asked if Mr. Ball could state through what lengths of pipe he had carried the mixture of sand and water; and what quantity of water in proportion to the solid material he found the best, according to the length of pipe passed through. It was easy to pass the stuff through open channels; but in some cases it might have to be sent a great distance, and if the flow was not regular and sufficiently fast, of course it would soon choke up. He should like to know also what was the indicated horse-power under given conditions, and the percentage of actual work done. That would give the loss by friction, which he fancied must be very great for long distances, if the pipe was small.

Mr. BALL said that the longest distance to which he had carried material through a pipe was the 1,200 yards already mentioned; but he had done that in two relays. After it reached 600 yards the back-pressure seemed to become too great—that was to say, the friction increased the resistance to the passage of the material so much that the pump was no longer able to force it through. He therefore established a second pump on a floating pontoon or barge, with a special engine; the delivery from the first pump entered into the suction of the second, and the two working

conjointly soon built up a very large mound on the banks of the canal that was being cut. In that case it was very fine sand. There was so much uncertainty with the different materials that these points could only be settled by practice in each case. Evidently, if there were heavy stones and so on, they did not roll easily, whereas very fine sand seemed to keep in suspension, and the friction was less. He had used a little device to prevent the material from settling at the bottom of the pipe, when running horizontally for long distances. He had formed a spiral rib in the pipe by means of a small angle-iron riveted along the inside, so as to make a long helix. The result was that the water in rushing through the pipe took up a rotary motion, and so kept the material from settling.

Mr. CRAMPTON said there must still be a minimum velocity, at which, if the material was sent, it would all settle. What was that minimum velocity as compared with the proportion of water to sand?

Mr. BALL said that was a question which he was not able to answer exactly, notwithstanding the numerous dredgers he had worked, because the circumstances varied continually. The same bottom did not work alike during half an hour. He might say generally that there were three elements in the problem: l the length of pipe; k the coefficient of friction, which for any given material could be made to vary by admitting more or less water; and P the engine power. There was a connection between these three quantities, which might be roughly expressed by the equation $P = k \times l$. Now if l were a fixed quantity, say 600 yards, and P also a fixed quantity, being the limit of the engine power, this equation could still be maintained, because k could be controlled by admitting a little more or less water. Supposing that in the progress of the work the distance l became doubled, it simply meant taking more water; and if the nature of the material changed, that affected k, but it could always be modified again by increasing or diminishing the admission of water, so as to satisfy the equation. Of course in practice the engine

power P could also be varied; for the engine was not supposed to be worked always to its very maximum, but to have at least a good third of its power in reserve. To give a single example, his so-called one-foot plant, that is, the plant of which the piping was 1 ft. diameter internally, delivered a maximum of 15 tons of water per minute; this gave a maximum velocity in the pipes of about 12 ft. per second, which he had found capable of carrying heavy stones, and even pieces of iron that got in by accident, as easily as so many straws.

Mr. Langley thought Mr. Crampton's question was partially answered at page 101; viz., that the best proportion of water to sand, according to actual experience, was 5 to 1. Of course that applied only to the case shown in Plate 8—a total lift of about 25 ft., of which the suction pipe drew about 12 ft., and then a horizontal travel of about 50 ft. further to the hopper barge. They found that 5 to 1 with that material answered best under those circumstances; but the proportion was sure to vary with the length of pipe, the distance to be carried, the material to be dredged, and the velocity. Very fine mud was held in suspension in water, and of course would go as far as the water went; but with sand it was different, as it continually sank downwards. Therefore water would carry with it a greater proportion of clay than of sand.

The President asked if there was not something peculiar in the form of the fan blades, which seemed to be very much curved at the ends. He should like also to ask how much space there was between the outside of the fan and the inside of the casing, and what clearance there was allowed beyond the edge of the india-rubber at each side.

Mr. Langley said the sides of the casing came very close to the metal blades, the clearance being $\frac{1}{2}$ inch; the india-rubber nearly touched, or did touch. The clearance between the front of the blades and the casing was about $4\frac{1}{2}$ to 9 in., the pump not being concentric.

Mr. Charles Hawksley said that, having had the advantage of seeing the dredger at work at Lowestoft on the occasion referred to by Mr. Skerrett, he could bear witness to the facility with which the dredger did its work, especially in the difficult position of having to dredge out of a pocket made in the side of the upright wall of the harbour, and also when dredging close to the foot of the piles which sustained the retaining wall. With regard to the difficulty experienced when dredging mud, in getting the mud to settle, it might perhaps be obviated by having three or four barges into which to discharge the delivery of the pump, dividing it equally among them, and not putting it into one barge at one point only, but say at a dozen points. The contents of each barge would then have time to subside, and allow the water to flow over the edge without carrying the mud with it.

Mr. Langley said they had tried a scheme which to some extent had answered the same purpose, by placing boards lengthwise in the barge, so as to cause the water to go from one end to the other several times, before finally it went over the side; but they found that, even with these precautions, about half the mud was lost.

Mr. Charles Hawksley said that plan would not have quite the same effect, because the water would be passing through narrow channels, and therefore its velocity would be retained; whereas if they passed it across and across the barge, letting it travel the whole length of the barge before going over, the velocity would be very much reduced; and if instead of employing one barge they employed four, of course they would again reduce the velocity to one-fourth of what it would be with a single barge.

Mr. Langley said no doubt something of that kind would prevent the loss; but to use so many barges together would cause such complications, that it would be better to use the ordinary bucket dredger.

Mr. E. A. COWPER thought it was due to the memory of Dr. Potts to say that he had been the first, he believed, who had proposed to excavate by vacuum. Many cylinder foundations for bridge piers had been excavated on his plan, which consisted chiefly in making a vacuum in a large reservoir, and then *suddenly* opening a large pipe connecting the reservoir with the cylinder to be excavated, when the great rush of water into the bottom of the cylinder brought in with it gravel, stones, sand, and mud, and allowed the cylinder to go down. He had himself sunk such a cylinder through 5 ft. $0\frac{1}{2}$ in. at one suck by such means, and stones the size of one's two fists were often drawn in. Dr. Potts had also proposed using a pipe from a vacuum reservoir to suck up stuff from the bottom into the reservoir.*

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* The following note, on other attempts of the same kind, has been communicated to the Secretary by Mr. William Anderson:—

"The principle of sucking up mud, sand, and gravel by means of centrifugal pumps has been familiar to me since 1864, when I saw, at the Chatham Dockyard Extension Works, a vertical-spindle centrifugal pump, by Messrs. Gwynne, fitted up as a mud dredger. Mr. Bernays, the resident engineer, writes to me that it was an entire failure, owing to the difficulty of getting the pump to the mud or the mud to the pump. When the pump was dropped down into a mud bank, a few revolutions brought up a wonderful stream of mud; but after it had brought up, in about half a minute, all the mud within range of the fan, it pumped nothing but water. The mud would not pull to the pump, and the pump could not be got to follow up the mud. The working was therefore quite spasmodic; and as the dredging lay in a tide way, where the bottom could be seen at low water, there was abundant opportunity of observing the action of the pump. The mud was removed in holes or trenches, and there was no symptom of any possibility of removing the mud from any given surface with the slightest regard to uniformity. At the best, the ground, after the pump had passed over it, looked like a celery bed. Mr. Bernays concludes by saying that he has often thought that the pump might be useful in pumping out of hopper barges on to land, the mud being fed up by hand. Some years ago I made a dredger for Demarara which acted on this principle; the mud was dredged up by an ordinary ladder, the buckets shot their contents into a centrifugal pump which was also supplied with water, and the mixture of mud and water was pumped over the canal banks. I have recently heard that this system has succeeded; certainly it worked very well in the Thames.

"Mr. H. Lee commenced experiments on sand pumps in 1872 or 1873, with the view of dredging the sand out of the North Sea entrance to the Amsterdam

Canal. He finally adopted a Woodford two-bladed fan about 4 ft. diam., working on an inclined or vertical spindle and always kept submerged. The pump consumed about 70 I.H.P. and raised 145 cubic metres of sand per hour; but the action was uncertain, and the bottom had to be finished with an ordinary dredger. The same effect appears to have been produced as that described by Mr. Bernays; the pump made holes and trenches. Mr. Lee would not use the pump again for large works, but thinks that in canals and narrow estuaries it might be useful, especially if the pump could deliver its contents over a bank; but even then the lead must be very short, as the power consumed increased rapidly with the length of the pipes. He found the same difficulty in filling the hopper barges as the author of the paper describes. Sand and gravel filled very well, but silt, mud, and peat would not subside fast enough.

"Mr. Lee did not encounter any of the difficulties Mr. Ball seems to have met with, probably because his pump was completely submerged, and hence all difficulties of charging and regulation were much diminished."

ON HYDRAULIC LIFTS FOR PASSENGERS AND GOODS.

BY MR. EDWARD BAYZAND ELLINGTON, OF LONDON.

It is only within the last ten or fifteen years that Lifts worked by mechanical power have come into general use; and, excluding docks and railway goods stations, it is still rather the exception than the rule to find power lifts in public buildings, or in warehouses and hotels even of considerable size. The greatly increased value of land in large towns, and the consequent increased height of the buildings erected, render however some kind of mechanical lifting power essential to the comfort and convenience of the occupiers.

Accidents to lifts, especially when worked by mechanical means, have been so frequent, that many hesitate to adopt them on account of the risk involved. But in a rapidly increasing number of cases their use is a necessity, and the risk must be taken. It becomes therefore a question of public importance that this risk should be reduced to a minimum.

In determining the question as to the best kinds of lift for passengers and for goods, it is necessary to premise that whatever system of lift is proved to be safest and best for passengers should also be adopted, where practicable, for goods. Workmen and others are in the habit of travelling in goods lifts, and a prohibition against this practice is productive of inconvenience. Considerations of expense however will often stand in the way of the adoption of the safest kind of lift for goods alone, especially when the height of lift is great; and there is in consequence a demand for two standard types, one for passengers and another for goods.

CHAIN LIFTS.

The first rudiment of a lift is to be found in the Hoisting Jigger, as commonly used in the Liverpool cotton warehouses: this consists of a winding drum, a cat-head pulley, and a chain attached to the

article to be raised, as shown in Figs. 1 and 2, Plate 10. By adding a cage and a guide to the chain, the apparatus has been developed into a lift. It is worked either by winch handles A, Fig. 2, or from a lower floor by the endless rope B. There are not many persons who would risk being hoisted in a sling to a considerable height; but when a cage is attached, the temptation to avoid the labour of ascent becomes great, and the individual enters, unwittingly staking his life on the security of the chain or rope supporting the cage.

Various attempts have been made to reduce or eliminate this risk. The favourite plan is to insert, above or below the cage, a safety apparatus, to retain the cage in position in case of the breaking of the chain or rope. Every few months a new safety apparatus crops up, always the most perfect that was ever invented, and warranted to stand the severest tests that can be applied. The apparatus is tested, and is found to work admirably, to the delight of the unfortunate victims who are to use it. A few years after, an accident happens, and, in the majority of instances, the safety apparatus is found to be a delusion; generally for the simple reason that no apparatus which is not in constant and necessary use is likely to be kept in proper working order. Moreover no safety apparatus with which the author is acquainted provides against all possible accidents to the machinery. Reasonable safety must be secured by some other means.*

In a chain hoist of any kind (where the word chain must be taken to include a hemp or wire rope), the first thing is to be sure of the chain or rope. If a chain be used, it should be of such strength that the ordinary load would not straighten the link out, even if it were cracked through. If wire ropes are used, there should be two, each capable of doing the whole work. The next point is the

* In one of a series of articles on "Elevators" in the American *Architect and Building News*, 1880, the following suggestive passage occurs:—"It is impossible to be too careful in the inspection of these appliances (viz. safety catches), whose action is very uncertain under the various unfavourable circumstances of actual use. Out of eleven elevators whose fall was reported during the month preceding that in which we write, it is said that only two were unprovided with what purported to be safety catches." Wire rope lifts are chiefly used in America.

attachments. The author's experience is that more accidents arise from the breakage of the attachments than of the chain. The attachments should be considerably stronger than the chain, and, where practicable, should be tested with it.

Having secured a good chain and attachments, the next question is as to the safety of the mechanism by which the chain is hauled in, and the cage lifted. There is a certain risk attached to a chain or wire rope, which cannot be removed; but it will obviously depend upon the mechanism adopted whether other risks are super-added. The chain may be hauled in by machinery worked by hand, steam, air, gas, electricity, or water; but there is generally very little distinction to be drawn between the machinery used with the first five of these motive powers;—given the gear, it is simply a question as to what force shall drive it.

Accidents may happen to any of the mechanisms adopted; and some of the elements of risk, with these various sources of power, may here be mentioned.

(*a*) Hand-power lifts are generally fitted with a brake apparatus, made up of several pieces; the giving way of any one of these would probably send the cage down with a run.

(*b*) The steam or air engine, in addition to the risk of breakage in the brake mechanism, is liable to breakage in the engine itself, and also in the gearing through which the power is usually transmitted; while the common practice of having clutches to throw the wheels in and out of gear adds a further risk of accident. Steam power is safer where worm gearing is adopted, and where steam is used for lowering as well as lifting; but this involves a great waste of power. In steam lifts there is also a considerable danger of accident from overwinding.

(*c*) The gas engine has all the risks attending the use of hand or steam power, and others besides; since, owing to the peculiar intermittent nature of its working, gearing is unsuitable for the first motion, and straps have to be used, which of all transmitters are the most dangerous. In a lift worked by a gas engine therefore, in addition to the necessary risk of a chain, there is the risk attending the use of driving straps and gearing in the working crab, and of

brake gear, the possibility of overwinding, the comparatively long time occupied in starting and stopping, and also the extra strain on the whole of the mechanism due to the shock of the explosions.

(*d*) The application of electricity to hoisting is at present only in its infancy; but so far as attempts have yet been made to obtain motive power by this means, its application would appear to be subject to the same defects as the other methods that have been considered.

(*e*) Finally there remains hydraulic power; and it is obvious that one source of risk is at once removed by employing water-pressure, namely that caused by the use of a brake apparatus; since in a hydraulic lift the descent is regulated by the speed at which the water used in lifting is allowed to exhaust. Water-power may be employed to haul the lifting chain through toothed gearing, or by means of straps, in which cases there still remain some of the risks inherent in the other systems; but by suitable arrangements all such mechanisms may be avoided, and the motive power may be obtained without in any way increasing the risk inherent to the use of a chain. This condition of relative safety is only obtained by taking care that the pressure of water on the hydraulic ram is directly transmitted to the hoisting chain. If the power is so applied, any derangement of the mechanism would either mean the stoppage of the lift, or its gradual descent owing to the escape of water from the lift cylinder. In the possible case of a burst cylinder or pipe, the same condition would hold good; while the friction of the ram in the stuffing-box would in itself perform the function of an automatic brake, in case of the too sudden escape of the contained water. The ram should also be provided with a positive stop, to prevent overwinding. The perfection of control obtained in hydraulic lifts is a further important element of safety. A single valve suffices for the control of all the motions of such lifts.

The form of hydraulic lift which most perfectly fulfils the above conditions for a chain hoist is that introduced by Sir William Armstrong, and known as the Hydraulic Jigger. Figs. 3 to 6, Plates 11 and 12, illustrate this the simplest type of a high-pressure hydraulic chain lift. In Figs. 3 and 4 the cylinder is horizontal, and the working pressure is

therefore constant. There is a loss of effect in this hoist, in consequence of the weight of the chain being balanced when the cage is at the bottom, and unbalanced when the cage is at the top. This loss might be partially avoided by placing the cylinder vertical and making the ram work upwards; but this would involve balancing the ram, otherwise it would increase the risk of accident; for, if the cage got fast, and if the valves were open to the exhaust, the ram might descend without the cage, and the cage might afterwards become suddenly released and fall. The lifting chain is sometimes balanced by letting the cage carry a loose chain below, which is coiled on the ground when the cage is at the bottom, and which is picked up by the cage as it ascends.

Fig. 6, Plate 12, is an illustration of a hydraulic jigger hoist suitable for moderate pressures. The ram A is inverted, and its weight partly balances the weight of the cage B. The chain C is attached at one end to the cylinder, at the other to the counterweights W. From the counterweights two wire ropes R are led to the cage, each being of sufficient strength to carry the weight. The author's experience is that wire ropes are not so reliable as chains, and that it is desirable where practicable to use duplicate ropes. In this hoist it will be observed that, owing to the inverted position of the ram, there is a greater head of water at the end of the stroke than at the commencement. But, as the lift is constructed, there is no loss of effect from this cause; for, the chain being more than twice the weight of the wire ropes, this extra weight assists the ascent of the cage at the commencement of the stroke, and thus compensates for the variation in head of water.

The hydraulic jigger is not generally applicable except for high working pressures; and high-pressure water is only occasionally available. Unfortunately therefore it is often necessary to depart from the beautiful simplicity of this apparatus. The best arrangement in such a case is to adhere to the hydraulic cylinder and ram, but to introduce a second chain into the multiplying gear. By doing so there is the additional risk due to the second chain and its attachments; but this extra risk is far less in proportion than

that of the lift chain itself, owing to the diminished speed and greater absolute strength of the first motion chain.

Figs. 7 and 8, Plate 12, illustrate a low-pressure hoist, suitable for pressures of 25 to 50 lbs. per sq. in., constructed as above described. In dealing with such low pressures it is essential to economy to save every foot of head, and to be very careful in the arrangement of the pipes, so as to avoid unnecessary bends. By putting the cylinder A below ground, and letting the ram work vertically upwards, the greatest economy is secured. The whole of the available head is then utilised, and the extra head of water at the beginning of the stroke of the ram compensates for the extra weight of the lifting chains which have then to be raised. It is necessary to balance the weight of the ram by counterweights B, both to save power, and also to ensure the ram being pulled down by the descending cage, and so to prevent the possibility of an accident from the cage sticking fast. The winding drum C of this hoist has two diameters, as shown in Fig. 14, Plate 14 ; on the smaller is coiled the lifting chain, and on the larger the cage chain, passing up to the bottom of the counterweights. The drum winds itself along a screw thread cut in the fixed supporting shaft, the pitch of the screw being equal to the pitch of the lifting chain wound on the drum. The lead of the chain is thus kept fair.

It will thus be seen that in properly constructed hydraulic chain lifts there is practically no element of danger beyond that incurred by the use of the chain or rope; and that on the score of safety, even in chain lifts, hydraulic power is to be preferred to any other.

Any of the chain lifts which have been considered may obviously be adapted for passenger use, without any modification of the mechanism in itself; but, in order to secure greater steadiness of working, and comfort to the users, the guides and working parts should be more carefully constructed. The controlling gear is arranged so as to prevent the too sudden starting and stopping of the lift; and the cage is furnished with seats, and is of a more or less ornamental character. Double chains and safety apparatus are often

introduced; but even where hydraulic gear is used, and all is done that is possible to secure safety, there still remains, in lifts so constructed, the considerable risk attaching to the use of chains or ropes for hoisting the cage. It is accordingly imperative, if passenger lifts are to come into more extended use, that some safer means should be adopted.

Direct-acting Lifts.

This safer construction is to be found in the case of those lifts which are not hoisted up from above, but pushed up from below, in such a manner that there is always a supporting column underneath the cage. Lifts have been constructed on this principle and worked by ordinary mechanical means, the supporting column being a rack, gearing into a pinion at the ground level; or, in another arrangement, the supporting column has a screw thread on its periphery, and is drawn up or down by means of a nut at the ground level. Looking to safety alone, it would not be possible to find fault with this latter arrangement; but the practicable speed of working must be extremely slow, and the power absorbed in friction very great. A hydraulic ram is clearly the right thing to use for the supporting column of the lift; and by adopting the direct-acting hydraulic ram, as shown in Plate 13, it would appear as if the question of absolute safety in lifts were solved. But it is soon found that there is something still required.

A hydraulic lift, with a vertical direct-acting ram, presents some rather curious problems in construction, which increase in difficulty as the height of lift is increased, and the working pressure reduced. A low-pressure lift of this type has to be made subject to the following conditions:—

(*a*) A well or bore hole has to be sunk to a depth somewhat greater than the height of the lift, in which well is inserted the lift cylinder;

(*b*) The ram has to be of an area sufficient, when acted upon by the pressure of water at command, to overcome friction, and to raise both the load and the surplus weight required for lowering the cage when empty;

(*c*) The weight, and also the displacement, of the ram increases with its height and diameter;

(*d*) The bottom of the well being usually far below the drainage level, the water used in working has to be forced up to the drain by the descending ram;

(*e*) The pressure upon the ram at any time during its motion will vary proportionally to the difference between the head of water and the height of lift at that time.

Under these conditions it will be seen that, with a simple ram, equilibrium cannot be maintained. With a given pressure and load to be lifted, there is a limit to the height of lift; the pressure on the area of the ram diminishing as the ram ascends. In ascending with a given pressure of water, the ram would run out a certain distance, and then stop; and in descending with a given weight it would descend a certain distance, and then stop.

It is therefore necessary to balance the varying displacement, in all high lifts working with low pressures of water. It is also necessary, in order to avoid great waste of power, to balance the weight of the ram.

The usual practice has been to introduce counterweights, and chains travelling over head sheaves, as shown in Fig. 11, Plate 14. The chains are of sufficient weight to balance the displacement of the ram. When the cage is at the bottom, the ram and cage are balanced by the weight of the counterweight *minus* the weight of the chain; and when the cage is at the top, the ram and cage are balanced by the weight of the counterweight *plus* the weight of the chain. The use of counterweights and chains unfortunately destroys the simplicity and absolute safety of the apparatus; for, though the risks attending the use of ordinary chain lifts are eliminated, and the chances of breakage are remote, there is still a reasonable possibility of accident.

In direct-acting hydraulic lifts the balance chain and weights entirely alter the character of the strains on the ram. For a considerable portion of its length from the top, the ram, instead of supporting the cage as a column, is thus really hanging from it: part of the ram is always in tension, and another part is always in compression, while the neutral plane varies in position according

to the pressure on the ram. Should the ram break above the neutral plane, or the attachment between the ram and cage give way, the cage would be violently dragged by the counterweight to the top, the fall being as it were upwards instead of downwards.* A lift so constructed does not therefore fulfil the conditions of safety required in a first-class passenger lift; and means must be found for doing away with the chains and counterweights, leaving nothing but the hydraulic cylinder, the ram, and the cage.

This condition can be obtained by increasing the working pressure, and by reducing the area, and therefore the displacement, of the ram; leaving only sufficient section to prevent its bending under the load, as shown in Fig. 9, Plate 13. The requisite safety is thus secured, but at a most extravagant expenditure of power, owing to the want of any balance; the expenditure due to weight of the ram and cage, and to the loss by displacement, being often five or six times that due to the net load. The author has erected several lifts on this plan, where it has not been necessary to provide special pumping plant to obtain the high pressure required. It would however be impracticable to adopt the arrangement as a general rule.

Messrs. Tommasi & Heurtvisé have designed a balancing arrangement separate from the lift cylinder, as shown in Fig. 15, Plate 15. The lifting cylinder A is in hydraulic connection with a second cylinder B of equal capacity, though of shorter stroke. In the second cylinder there is a loaded ram C, of sufficient weight to balance the minimum weight of the lift-ram and cage when at the bottom. This heavy ram works through the stuffing-box of a third cylinder D, of the same capacity as B; and the pressure of water in this third cylinder lifts the net load. Heavy chains E are attached to the ram C, between the two short cylinders, to balance the varying displacement of the ram A as it travels. This plan is satisfactory as regards safety, but the weight and size of the cylinders and moving parts are so great as to render its adoption on a large scale impracticable.

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* This happened at the Grand Hotel in Paris, when several passengers were killed.

Hydraulic Balance Lifts.

The author has endeavoured to overcome the above-mentioned difficulties; and has devised an arrangement which appears to him to meet all the requirements of a perfectly safe, rapid, and economical passenger lift. The conditions of the apparatus are as follows:—

(*a*) The motive power is water, either at high or low pressure;

(*b*) The ram is always in compression, and supporting the load directly;

(*c*) The dead weight of the ram and cage is balanced wholly or partly by hydraulic pressure;

(*d*) The displacement of the ram is reduced to a minimum, and is balanced without any special mechanism;

(*e*) The weight of the moving parts of the lift is reduced to a minimum;

(*f*) No part of the machinery or supports is above the cage;

(*g*) There is no part of the machinery which, by giving way, could reasonably be expected to cause an accident to those ascending or descending in the lift.

This Hydraulic Balance Lift is shown in Plate 16. The hydraulic lifting cylinder, ram, and cage are as usually made, except that the ram is smaller in diameter. Its size is determined by the strength required to carry the load, and not by the working pressure of water available. As in Tommasi's lift, the lift cylinder A, Fig. 16, is in hydraulic connection with a second and shorter cylinder B, below which is a cylinder C of larger diameter. There is a piston in each, connected by the ram D, Fig. 17. The capacity of the annular space JJ below the upper piston is equal to the maximum displacement of the lift ram A. The annular area E of the lower piston C is sufficient, when subjected to the working pressure, to overcome friction and lift the net load; and the full area B of the upper piston is sufficient, when subjected to the same pressure, to balance within a small amount the weight of the ram and cage when at the bottom. When the parts of the apparatus are properly proportioned, the lift ram and the balance pistons are in

equilibrium in every position; or, in other words, the displacement of the ram of the lift cylinder is automatically balanced.

The mode of action of the lift is as follows. Assuming the cage to be at the bottom of its stroke, the valve is opened from the cage by means of a rope or system of levers, and pressure is thereby admitted to the annular area of the lower piston at E. The top of the upper piston is always subjected to the same pressure. The pressures on the two pistons thus act in the same sense on water in the annular space J, below the upper piston; and the intensified pressure of this water is transmitted through the pipe H to the lifting ram A, which thereupon ascends. As it ascends, the ram increases in apparent weight, but at the same time the pistons B and C descend, and are thereby subjected to an increasing head of water, which increased head, acting upon the large area of the pistons, exactly balances the increase of weight of the ram, or—to state the case more accurately—compensates for the loss of effective head in the lift cylinder. When the ram reaches the top of its stroke, the valve is closed, and the lift stops. On opening the valve to the exhaust, the pressure is relieved from the space above the piston C, while the piston B remains subjected to the working pressure above it, as in ascending. The lift now descends: the weight of the ram and cage, pressing upon the water in the lift cylinder, transmits the pressure to the annular area at the bottom of the piston B, and overbalances the weight of the pistons and the pressure on the top of the piston B. As the lift ram descends into its cylinder, it displaces the water and loses weight, or, in other words, encounters an increased resistance to its descent. At the same time the two balance pistons ascend, and the pressure above each of them decreases; the decrease in the pressure being in proportion to the increased pressure on the area of the lift ram. The lift ram and the pistons B and C are, as stated, in constant equilibrium. To make good any possible leakage, provision is made for admitting the working pressure through the cock F under the piston C, and so raising it, while the cage is at the bottom; this relieves the pressure in the annular intensifying chamber J, and allows water from above the upper piston B to flow down past the packing leather of that

piston and replenish the space J. As a general rule, the part of the lower cylinder underneath the piston C is not filled with water in the regular working of the lift, but is open to the atmosphere. If however the cock F controlling the admission is closed, during the descent of the cage the rising of the piston C creates a vacuum beneath it, which becomes available as lifting power for the next ascent. In other words, the weight of the descending load is by this means utilised to augment the lifting power in the next ascent of the loaded lift; or, if the lift is being used for the purpose of lowering goods, the vacuum supplies power enough for raising the empty lift without the expenditure of any water at all.

The author's hydraulic balance lift permits of great variety of application; and the proportions of the balance cylinders may be adjusted to suit any working pressure available, without alteration to the size of the lift ram. This facilitates the employment of high working pressures; and the system is therefore particularly adapted for use in connection with public distribution of hydraulic power on the high-pressure or accumulator system, where economy in the use of the power is of vital importance. When working the lift with high pressure, the balance cylinders may be temporarily disconnected, and the pressure used direct from the accumulator.

The increase of the working pressure reduces the size of the lift cylinder, and also much increases the speed of the lift—a matter of great consequence in public offices, and other places where large numbers of passengers have to be accommodated. The author has for some time past adopted a working pressure of 200 lbs. per sq. in. and upwards for high direct-acting lifts; and by so doing has succeeded in working these lifts at a speed of 200 ft. per minute, and, with a single lift taking five or six people at a time to a height of about 40 feet, in accommodating as many as 3000 passengers in the course of nine hours.

When using high-pressure water from an accumulator for working the hydraulic balance, it is not necessary to use the high pressure for the balance piston. Water may be taken for this purpose from a supplementary tank, placed at any convenient height; or the fluid used may with advantage have a higher specific gravity than water.

The water is taken from the tank and returned, at each ascent and descent of the lift cage. In many cases of high-pressure lifts the loss by displacement of the ram is not of sufficient consequence to be considered: then the arrangement adopted is as shown in Figs. 18 and 19, Plate 17, and the balance cylinders can, if desirable, be placed horizontally. Here the working pressure due to the area of the central pipe B acts constantly to balance the minimum weight of the ram and cage; and the lifting power is obtained by admitting the working pressure into the outer annular space EE, and so forcing water from J through the pipe H to the lift cylinder A.

Another incidental advantage of the Hydraulic Balance lift is that the space in the lift well, usually occupied by the counterweights and guides, is available for the cage. All head gear is avoided, and no special structural arrangement for carrying the weight from above is required.

Having thus described what the author regards as the standard form of lift for passengers and goods, it is necessary to remark that it is still possible for serious accidents to happen, unless attention is paid to the protection of the lift well, and to the method of working the lift. To work with safety and at a high speed, the lift well should be cased in, and closed by doors opened only from the inside of the lift. Doors should also be provided in the cage, though these may be dispensed with if care be taken to make the cage fit close to the framing of the lift well, the doors and boards being flush from top to bottom, so that they make a sliding joint with the cage. It is also desirable that the lifts should be worked by an attendant, especially in high-speed lifts, where it is necessary to be careful in handling the rope, to avoid jerks at starting and stopping. When lifts are not worked by an attendant, special arrangements of the controlling gear and doors are necessary, to prevent the doors from being opened while the lift is in motion, and to render the control of the lift as far as possible automatic.

Economy of Hydraulic Lifts.

Having arrived at the conclusion that for practical purposes the only really secure lifts are those worked by hydraulic pressure

applied on the direct-acting principle, without the aid of any balance chains or counterweights, it will be interesting to consider how far hydraulic power is to be preferred upon the ground of economy.

This question can be brought to a very simple test. Hydraulic apparatus, as used in hydraulic lifts, forms a system of mechanism for the transmission of power, and the relative economy of the prime movers need not for the present be considered.

On the one side we may place the direct-acting hydraulic lift, and on the other an ordinary geared lift. In both lifts the friction of the cage and its balance are the same, assuming the friction of the hydraulic balance to be equal to that of the balance-weight and chains which it supersedes. Which force then will give the greatest efficiency: power acting by fluid pressure, on a ram passing through a single stuffing-box or leather, or the same power acting through ordinary gearing, and finally winding the lifting chain upon a drum? The loss of useful effect from the latter cause alone may equal that due to the friction of the ram. Where the water pressure is available without pumping, the question of relative economy, as between hydraulic and ordinary gearing, does not require argument; that hydraulic gear is the most economical is sufficiently obvious.

But there are of course other considerations besides the friction of the machinery employed. If mechanical means have to be provided for obtaining the water pressure, it may be that the loss in first producing this pressure, and then applying it through an economical machine, may be greater than in applying the original power direct through an extravagant machine; or, owing to the peculiarity of hydraulic machinery, in involving, within narrow limits, an invariable expenditure of power, the loss of useful effect may more than compensate for diminished friction.

Now a steam engine working an accumulator gives an efficiency of 75 to 80 per cent. The loss between the work stored in the accumulator and the work done by a direct-acting ram may be taken at 5 to 10 per cent.; which would give a final efficiency of say 70 per cent. No geared lifting machinery, driven direct by a steam engine, gives anything approaching so high an efficiency; and the efficiency would again be much lowered if, as in the generality of

cases, the steam engine had to be kept constantly moving. The loss from this latter cause is much greater than the loss arising from the invariability of the hydraulic lifting power: moreover, though the power of hydraulic lifts is invariable, yet when lifting light loads there is a gain of speed.

The comparison between geared and hydraulic lifts is not in any way affected to the advantage of the former, by substituting a gas engine for the steam engine and boiler. The gas engine cannot drive direct, owing to its high speed; and it must be kept constantly going, since to start it takes time and labour. There can be no question that the efficiency of a gas engine is far less than that of a steam engine doing the same work; but this loss is in many cases compensated by the cheapness of the explosive power, and the convenience of having no boiler. These advantages of the gas engine are retained, by using it to obtain the hydraulic pressure; and the fact of its having to work constantly renders pumping against a constant head a peculiarly suitable occupation for it.

Until therefore it can be shown that the use of hydraulic pressure with a direct-acting ram entails more friction than a system of ordinary gearing to do the same work, hydraulic power will remain the most economical as well as the safest agent for direct lifts. The efficiency of the hydraulic jigger varies of course with the multiplying power; but the same argument holds good for the jigger as for the direct ram, though to a diminished extent.

There remains the question of first cost. On this point the author's view is:—

1st. Where safety is concerned, cost should be a secondary consideration;

2nd. The cost of hydraulic machinery, where the hydraulic pressure is already at hand, is no more than that of any other system;

3rd. The extra cost required, where the pressure is not at hand, is as a general rule amply compensated for by the greater safety, the greater general efficiency, the greater economy in working, and the diminished wear and tear of the machinery.

LIFTS OF LARGE POWER.

Thus far only lifts of small power, for hotels, warehouses, &c., have been dealt with; as to which there exists a great variety of practice. Plates 18 and 19 are illustrations of hydraulic lifts of greater power, and possessing some novel features.

Plate 18 illustrates the direct-acting hydraulic lifts erected at Seacombe pier on the Mersey, to take the carts and wagons from the floating landing stage to the high level. The height of lift is 32 ft., and the net load 20 tons. The lifts were designed by Mr. Wm. Carson, M. Inst. C.E., to avoid the long approaches used at Woodside, and at the Liverpool landing stage; and they have most perfectly fulfilled their object. Owing to the weight of the ram and cage being unbalanced, the efficiency is low; but in this instance, as the rams are working in a tideway, Mr. Carson no doubt exercised a wise discretion in avoiding the complication of a balancing ram, or other balancing apparatus. There is however a connecting valve between the two lifts, so that a descending load in one lift may raise the other cage when required. The hoists are made to accommodate railway coal wagons, which can, if necessary, be taken across the river on the ferry boats. The platform upon the cage is double; the upper portion B slides longitudinally upon the lower, and is guided to the radius of the bridge connecting the floating stage C with the upper pier. This bridge is hinged at both ends, and the guiding arcs A are struck with a radius of 160 ft., equal to the length between the hinges.

Plate 19 illustrates another arrangement of wagon hoists, constructed for the Midland Railway Company at Whitecross Street station on the Metropolitan Railway. The object of the arrangement was to get a direct-acting hoist without sinking a well, the condition being that the concrete floor of the station should not be touched. There are two lifting rams at each side, placed in hydraulic connection diagonally, so that either two or four can be used, the lifting force in either case passing through the centre of gravity of the platform. When lowering loaded wagons, the water used to lift

the platform alone, or with only an empty wagon on it, is returned to the reservoir by the descending load.

For such lifts as these, direct-acting hydraulic rams are now almost exclusively used. That direct-acting hydraulic apparatus has not been more generally employed for small lifts is due, in the author's opinion, rather to the mechanical difficulties in the way, than to any doubt as to their superiority, whether used for heavy or light loads.

In conclusion the author would remark that he has left many varieties of hydraulic lifts untouched. He has dealt almost exclusively with a special class of lifts, which he considered to possess several points of interest; and he has confined himself, with one or two exceptions, to machinery constructed under his own supervision by the Hydraulic Engineering Company of Chester.

In the appended Table I. are given the results of a number of observations on the relative economy of hydraulic lifts of different kinds, and working at different pressures.

HYDRAULIC LIFTS.—Table I.

No. of Expt.	Description of Lift.		Pressure of Water.	Diameter of Ram.	Stroke of Ram.		Height of Lift.		Ratio of Height of lift to Stroke of ram.	Net Load lifted.			Speed of Ascent.		Speed of Descent. Cage Empty.	Efficiency of Machine, ascending with full load. *
													Cage Loaded.	Cage Empty.		
	Plate.	Fig.	lbs. p. sq. in.	In.	ft.	in.	ft.	in.		cwt.	qrs.	lbs.	Ft. p. min.	Ft. p. min.	Ft. p. min.	per cent.
1	12	7	28	14	7	6	43	6	5·8	3	2	0	40	136	112	76·3
2	12	7	30	18	9	0	45	0	5	7	2	0	28	96	66	77·5
3	16	16	$33\frac{1}{2}$	$3\frac{1}{2}$	50	6	50	6	1	8	0	0	35	138	47	80·0
				$21\frac{3}{4}$–11	8	2			6·2							
4	12	7	34	23	7	2	57	4	8	9	0	0	29	107	62	78·5
5	12	7	39	17	9	2	72	4	7·9	6	0	0	55	145	98	79·9
6	14	11	$39\frac{1}{2}$	6	49	6	49	6	1	5	0	23	30	103	57	76·1
7	14	11	40	$8\frac{15}{16}$	73	6	73	6	1	12	2	20	19	68	71	78·1
8	12	6	190	$13\frac{1}{2}$	9	0	90	0	10	13	0	0	57	222	62	76·8
9	14	11	200	$4\frac{1}{4}$	79	0	79	0	1	15	2	0	47	235	156	80·6
10	17	18	640	$3\frac{31}{32}$	57	0	57	0	1	32	2	0	60	265	48	85·0
				$11\frac{1}{4}$–$6\frac{5}{8}$	7	$1\frac{1}{2}$			8							
11	11	3	740	$4\frac{3}{4}$	6	9	54	0	8	8	0	0	60	648	81	77·5
12	11	3	790	5	7	2	71	8	10	7	3	18	53	427	82	78·5

DESCRIPTION OF LIFTS.

Experiment No. 1.—Plate 12, Fig. 7.—Chain Lift with balance weight. No safety gear.
„ No. 2. „ „ „ „ „ „ „ With safety gear.
„ No. 3.—Plate 16, Fig. 16.—Direct-Acting Ram. Author's Hydraulic Balance Lift. (Low pressure.)
„ No. 4.—Plate 12, Fig. 7.—Chain Lift with balance weight. Safety gear. No winding drum.
„ No. 5. „ „ „ „ „ „ „ No safety gear. Rollers to cage.
„ No. 6.—Plate 14, Fig. 11.—Direct-Acting Ram, with balance chain and weight.
„ No. 7. „ „ „ „ „ „ „ „ „ „
„ No. 8.—Plate 12, Fig. 6.—Chain Lift with balance weight.
„ No. 9.—Plate 14, Fig. 11.—Direct-Acting Ram, with balance wire-ropes and weight.
„ No. 10.—Plate 17, Fig. 18.—Direct-Acting Ram. Author's Hydraulic Balance Lift. (High Pressure.)
„ No. 11.—Plate 11, Fig. 3.—Chain Lift with balance weight. Safety gear. Vertical cylinder.
„ No. 12. „ „ „ „ „ „ „ No safety gear. Horizontal cylinders.

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* NOTE.—The efficiency of the machine $= \dfrac{\text{Weight lifted} \times \text{height}}{\text{Pressure} \times \text{area of ram} \times \text{stroke}}$.

There are however three elements to be considered: (1) the friction of the machine during ascent, (2) the net load lifted, (3) the friction of the machine during descent, represented by the additional load lifted in the unbalanced weight of the cage.

If, in calculating the efficiency as above, the net load only is taken, the total loss by friction both in ascending and descending is debited to the ascent alone. The percentage of efficiency in the Table assumes the friction during ascent and descent to be equal, and gives the efficiency during ascent only.

COMMITTEE ON RIVETED JOINTS.

EXPERIMENTS ON HIGH BEARING PRESSURES, SERIES X.

REPORT BY PROF. ALEX. B. W. KENNEDY.

(*Published by order of the Council.*)

Table XXVIII., annexed to this Report, gives the results of a set of experiments directed specially to the determination of the effect of very High Bearing Pressures upon Riveted Joints of the type already experimented on.* In the former experiments there were no joints in which the pressure on the rivets at fracture much exceeded 40 tons per sq. in. The experiments, so far as they bore on this point (see Proc. 1881, p. 221), were thought to indicate that this pressure determined the joint to give way by shearing; but the evidence was very incomplete, and the following experiments were carried out in order to obtain more definite information on the matter. Its practical importance is this:—that all the experiments have pointed to the advantages to be gained from using the largest possible rivets, but while the area of the rivet increases as the square of its diameter, its bearing surface increases only as its diameter, so that the intensity of pressure on the rivet surface becomes proportionately greater as the diameter of the rivet is increased. With single-riveted lap-joints practical considerations mostly keep the diameter of the rivet below any size at which the pressure would become too large. But in such joints as some of those about to be tested (double-

* In the last Report (see Proceedings 1881, p. 712, &c.) it should have been mentioned that the joints prepared by Messrs. John Penn and Sons were held up in the usual way by hand, and not riveted up on an anvil.

riveted butt-joints, for instance) this increase of bearing pressure may (and actually does) keep the diameter below the limits which would otherwise be quite practicable and convenient.

Series X. consists of eight single-riveted lap-joints, four of $\frac{1}{4}$-in. and four of $\frac{3}{8}$-in. plate. The specimens used were the similarly numbered ones of Series V. and VA. (see Tables XII. to XV., Proc. 1881, pp. 243–6), the fractured ends being slotted off and the two halves then riveted together. The exact strength of the pieces tested, with the increase due to the perforation, was thus known from the former experiments. In each case the joint was made with two rivets, the diameter of the (drilled) holes being 1·1 in. The pitch of the rivets in the $\frac{1}{4}$-in. plate was 3·7 in., in the $\frac{3}{8}$-in. plate 2·8 in., the total breadth being two pitches in each case, and the margin equal to diameter of hole. The riveting was done by hand as before, and the rivets were made with heavy heads and ends. The drilling and riveting was done by Messrs. George Wailes & Co., the testing by the writer at University College.

The first two joints given in the Table, Nos. 322 and 323, belonged originally to Series V. They were of $\frac{1}{4}$-in. plate, having a tenacity of 34·5 tons per sq. in. in its original state, and 38 tons per sq. in. after drilling. These joints broke at almost identical loads. When the pressure on the rivets reached about 55·5 tons per sq. in., the rivets sheared at a stress of 17 tons per sq. in. The tension on the plate at the same time was 23·6 tons per sq. in. In each case one rivet gave out before the other, so that the stress had not been equally distributed at fracture; while not one of the joints formerly tested, so far as the writer remembers, broke in this way. The joints showed a resistance equal to 48 per cent. of the same breadth of solid plate.

The two joints Nos. 455 and 457 belonged to Series VA.; they were also of $\frac{1}{4}$-in. plate, but of softer quality than the last, having a tenacity of 29 tons per sq. in. unperforated, and about 33 tons per sq. in. after drilling. The particular metal used in No. 455 was however considerably softer than the average, having a tenacity, when perforated, of only 28·6 tons per sq. in. Quite consistently this joint now gave way at 49·4 tons per sq. in. pressure on the rivets, by

the shearing of the rivets at a stress of only 15·7 tons per sq. in., the stress on the plate being only 20·9 tons per sq. in. The second joint gave way similarly at a shearing stress of 16·8 tons per sq. in., when the bearing pressure reached 53·1 tons per sq. in., the stress on the plates being 22·4 tons per sq. in. The strengths of the joints were respectively 50·6 per cent. and 54·1 per cent. of that of the solid plate. In each case one rivet gave way before the other.

With the $\frac{1}{4}$-in. plates the results were therefore very uniform; in the following experiments, where $\frac{3}{8}$-in. plates were used, the results are unfortunately not so consistent, although quite similar in their general tendency.

Nos. 326 and 327 (the same pieces as 326–3 and 327–3 of Series V., Table XII.) show the greatest difference. In the former the joint gave way by the shearing of the rivets (one before the other) at 18·14 tons per sq. in., when the pressure upon them was only 42·9 tons per sq. in. The simultaneous stress in the plate was only 27·8 tons per sq. in., and the joint gave 53·7 per cent. of the strength of the solid plate. There is nothing to show to what extent the pressure on the rivets became unequal before fracture, but the distorted condition of the plate makes it easy to suppose that the inequality was considerable. (The form of one of the ends after fracture is shown in Plate 20.) In No. 327 the joint nearly attained its full strength; it gave way by the plate tearing (the tearing however beginning distinctly at one edge first) when the stress reached 32·5 tons per sq. in., while the same plate perforated had originally given 34 tons per sq. in., or only 1·5 ton more. The shearing stress reached 21·4 tons per sq. in., while the bearing pressure was just over 50 tons per sq. in. The joint attained 63 per cent. of the strength of the solid plate: if the full resistance of the plate could have been reached the proportionate strength would have been 66 per cent., this large value being due to the use of the large rivets.

The two remaining $\frac{3}{8}$-in. joints, Nos. 459 and 461 (the same as 459–3 and 461–3 of Series VA., Table XIV.), were of softer material, and their results were more concordant. The plate originally stood 28·9 tons per sq. in. plain, and 32 tons per sq. in. drilled. Both

joints gave way in the plate. The first tore uniformly across at 30·14 tons per sq. in., with a bearing pressure of 47 tons per sq. in. In the second, tearing began at one edge and thence extended right across, at a pressure of 43·9 tons per sq. in., and a tensile stress of 28·2 tons per sq. in. The shearing stresses were respectively 20·9 and 19·7 tons per sq. in. The first joint gave a strength of 63·6 per cent. and the second 59·5 per cent. of the solid plate.

In all cases the joints began to slip at very low loads—generally about one-tenth of the breaking loads; and the slipping appeared to go on continuously, though slowly, after it had begun. It was observed by aid of a magnifying glass, as in the former experiments. In Nos. 455 and 457 however, slip was not visible until about one quarter of the breaking load was reached, and then only increased very slowly.

The writer thinks that the following conclusions may be drawn from the comparison of the results of these experiments with the results of the former experiments on the same material.

(I.) High bearing pressure, with the materials used in these experiments, weakens the joints mainly by causing such distortion of the metal that the stress becomes very unequally distributed, the intensity of stress at the point where fracture begins being much greater than its calculated *average* value.

(II.) A pressure of from 50 to 55 tons per sq. in. may bring down the (apparent) shearing resistance of the rivets about 25 per cent., and cause fracture by shearing at a correspondingly low stress. (The negative result of No. 327 can hardly be looked upon as other than exceptional.)

(III.) A pressure as small as 42 or 43 tons per sq. in. *may* cause inequalities of stress sufficient materially to weaken the joint.

(IV.) A joint weakened in this way may break eventually either by tearing the plate or by shearing the rivets.

It has here been assumed that the inequality of stress shown to exist by the manner of fracture—*an inequality which did not appear in any of the former experiments*—was due to excessive bearing pressure, as it was only in this one point that these joints differed

from the former ones. The only other reason which suggests itself for this inequality would be that the large rivets had not properly filled their holes, of which however there is no visible sign.*

The writer therefore thinks that with the materials used in these experiments it would be practically inexpedient to design a joint, in which the calculated bearing pressure on the rivet should exceed say 42 or 43 tons per sq. in. With single-riveted lap-joints this practically allows the rivets to be made as large as it would ever be convenient to make them, but with joints where the rivets are in double shear (butt-joints with double covers), it may often happen that the size of the rivets has to be kept down in order that the pressure may not exceed that mentioned. In all cases when the pressure is large, it would seem very advisable to allow extra *margin* on the joint. By preventing distortion of the plates this might materially increase the resistance.

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* The writer is informed that in the experiments of Mr. W. R. Browne, given in Proceedings 1872, p. 72, when iron joints gave way at extremely low tensile stresses under a bearing pressure of 38 to 42 tons per sq. in., the plates began to tear at one edge, showing the same inequality of stress as that here observed.

RIVETED JOINTS.—TABLE XXVIII.

SERIES X.—GENERAL RESULTS.—LAP-JOINTS WITH HIGH BEARING PRESSURES—(*Single-Riveted Steel Plates. Two Rivets.*)

I. Series.	II. Test Number.	III. Dimensions. (Pitch always equal to half breadth.) Thickness In.	IV. Breadth In.	V. Diameter of Hole. In.	VI. Total Breaking Load. Lbs. & Tons.	VII. Tearing Area. Sq. In.	VIII. Tensile Stress at fracture per sq. in. Lbs. & Tons.	IX. Shearing Area. Sq. In.	X. Shearing Stress at fracture per sq. in. Lbs. & Tons.	XI. Bearing Area. Sq. In.	XII. Bearing Pressure at fracture per sq. in. Lbs. & Tons.	XIII. Original Tenacity. Average of Solid Plate. Tons per sq. in.	XIV. Same pieces Perforated. Tons per sq. in.	XV. Proportional Strength of Joint. Per cent.	XVI. Remarks.
From Series V. (*See* Proceedings 1881, p. 243.)	322–4	0·264	7·39	1 1	72200 32·23	1·365	52890 23·61	1·9	38100 16·97	0·581	124300 55·48	34·5	drilled 37·9	47·9	Sheared (one rivet first).
	323–4	0 263	7·41	1·1	72380 32·31	1·370	52830 23·59	1·9	38100 17·01	0·579	125000 55·82	34·5	drilled 38·1	48 1	Ditto
	326–3	0·365	5·60	1·1	77200 34·47	1·241	62210 27·77	1·9	40630 18·14	0·803	96140 42·93	31·4	drilled 35·4	53·7	Ditto
	327–3	0 365	5·62	1·1	90900 40·58	1·248	72830 32·52	1·9	47850 21·36	0·810	112200 50·10	31·4	drilled 34·0	63·0	Tore plate from bottom edge.
From Series VA. (*See* Proceedings 1881, p. 245.)	455–4	0·275	7·41	1·1	67000 29·91	1·431	46720 20·86	1·9	35260 15·74	0·605	110700 49·45	29·0	drilled 28·6	50·6	Sheared (one rivet first).
	457–4	0·271	7·42	1·1	71700 32·01	1·430	50140 22·38	1·9	37740 16·85	0·603	118900 53·09	29·0	punched 33·2	51·1	Ditto
	459–3	0·384	5·63	1·1	89000 39·74	1·313	67530 30·14	1·9	46850 20·92	0·845	105300 47·03	28·9	drilled 32·0	63·6	Tore fairly.
	461–3	0·387	5·63	1·1	83800 37·41	1·328	63100 28·17	1·9	44100 19·69	0·852	98360 43 91	28·9	punched 29·4	59 5	Tore plate from bottom edge.

Parkinson Meter, 5/8 inch.

Fig. 1.

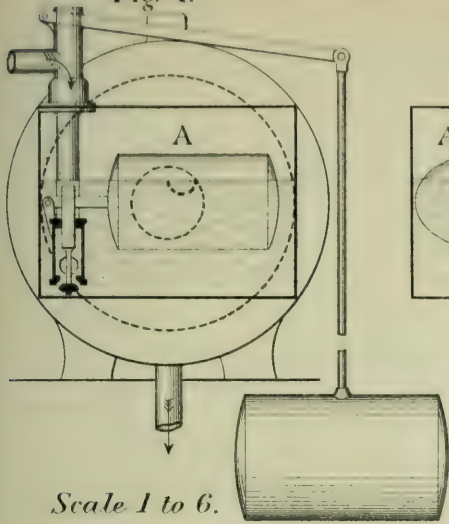
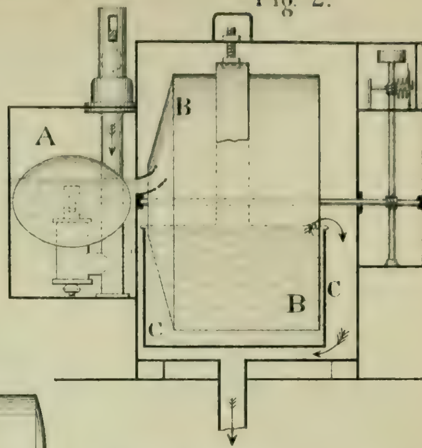


Fig. 2.



Scale 1 to 6.

Kennedy Meter, 1/2 inch.

Fig. 3.

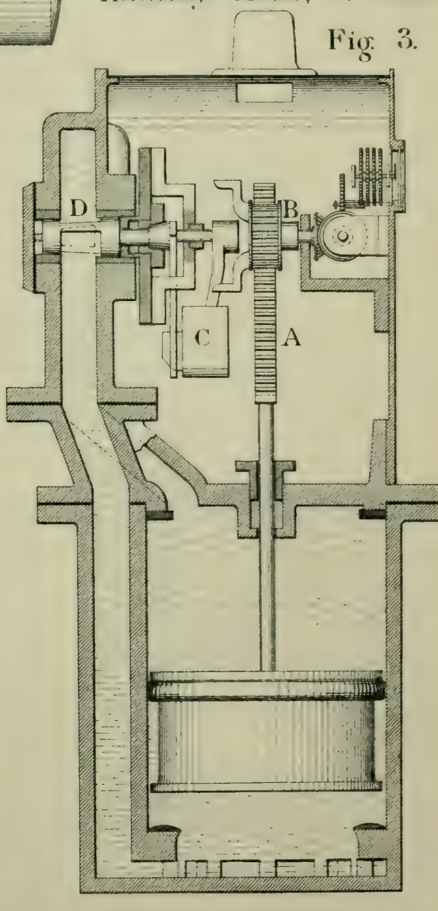
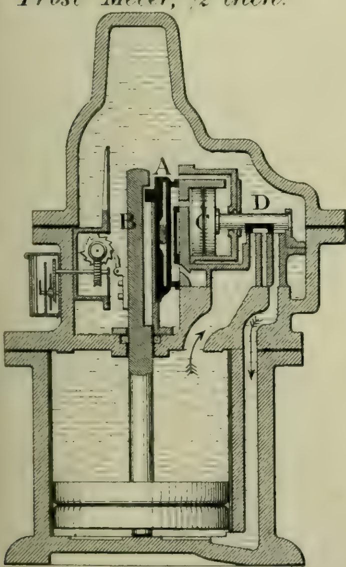


Fig. 4.

Frost Meter, 1/2 inch.



Scale 1 to 6.

(Proceedings Inst. M. E. 1882.)

Fig. 5. *Siemens Turbine Meter.*

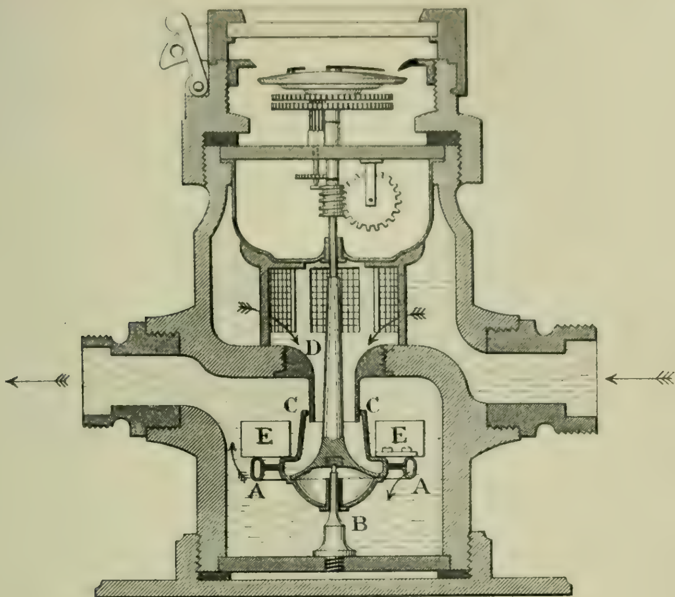
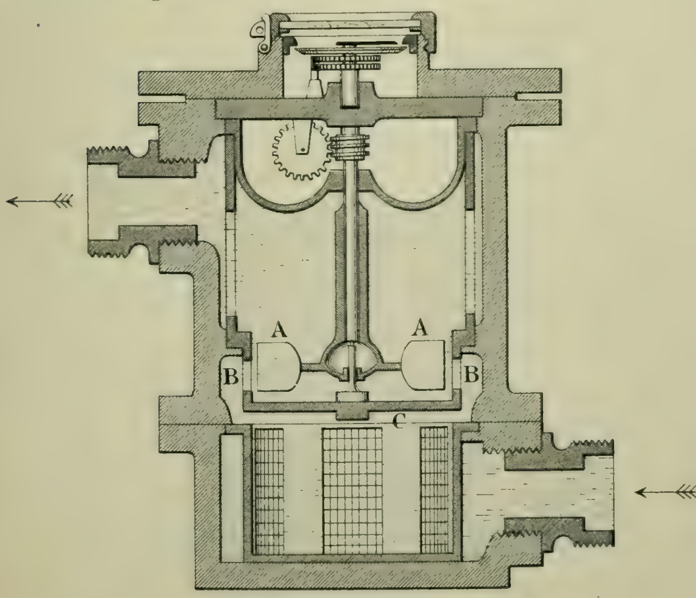


Fig. 6. *Siemens Fan Meter.*



 One third full size.

Tylor Meter, 1 inch.

Fig. 7.
Section.

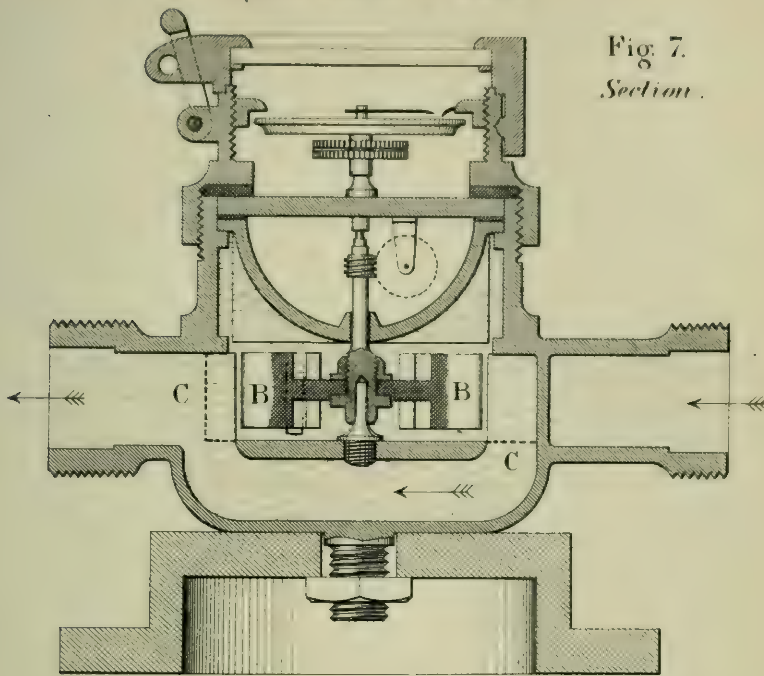


Fig. 8.
Sectional Plan.

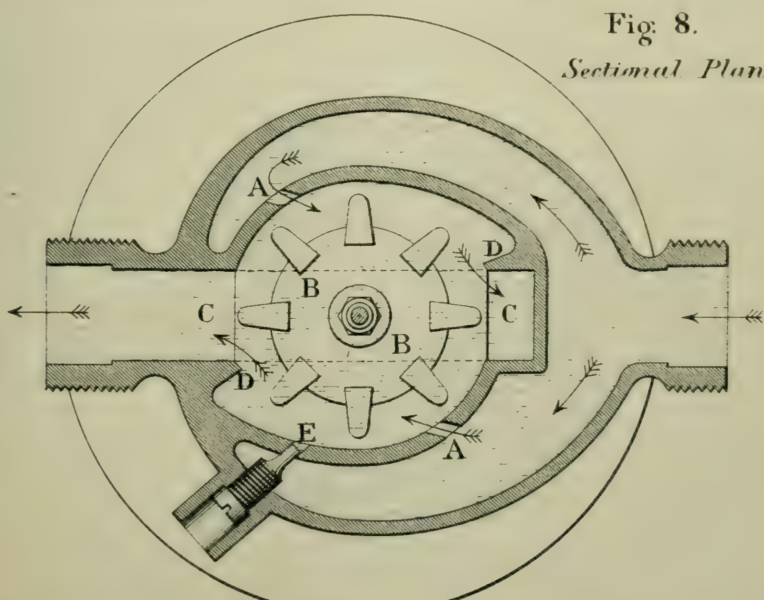


Fig. 9. *District Meter Diagram, Bridgwater.*

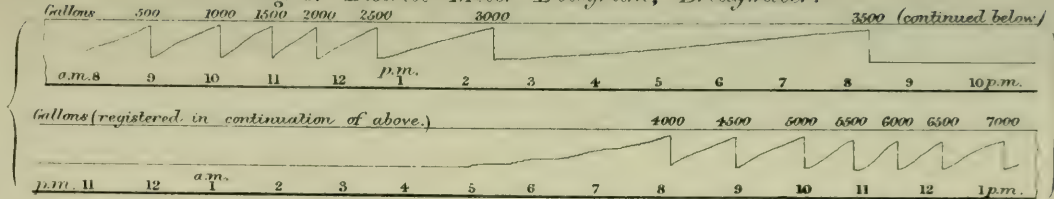


Fig. 10. *District Meter Diagram, Lambeth, (before inspection).*

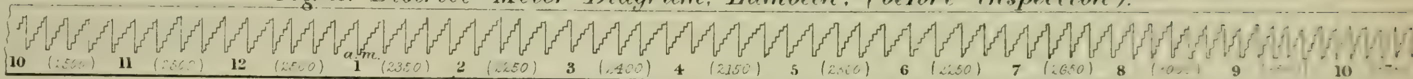


Fig. 11. *District Meter Diagram, Lambeth, (after inspection).*

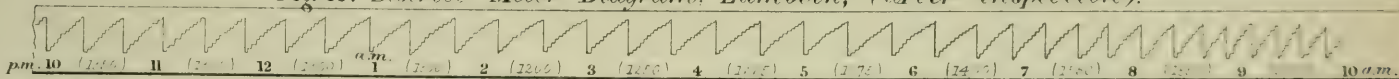


Fig. 12. *Inspection Diagram, Lambeth, (results of shuts-off).*

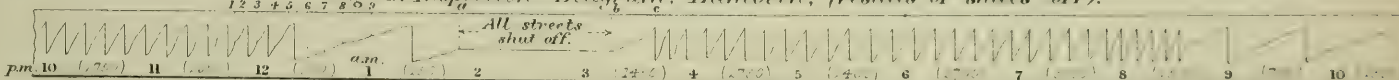


Fig. 13. *District Meter Diagram, Reading, (before inspection).*

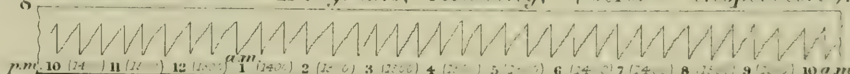
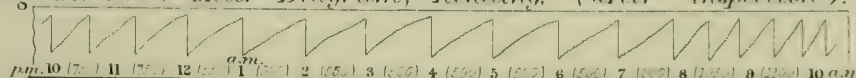
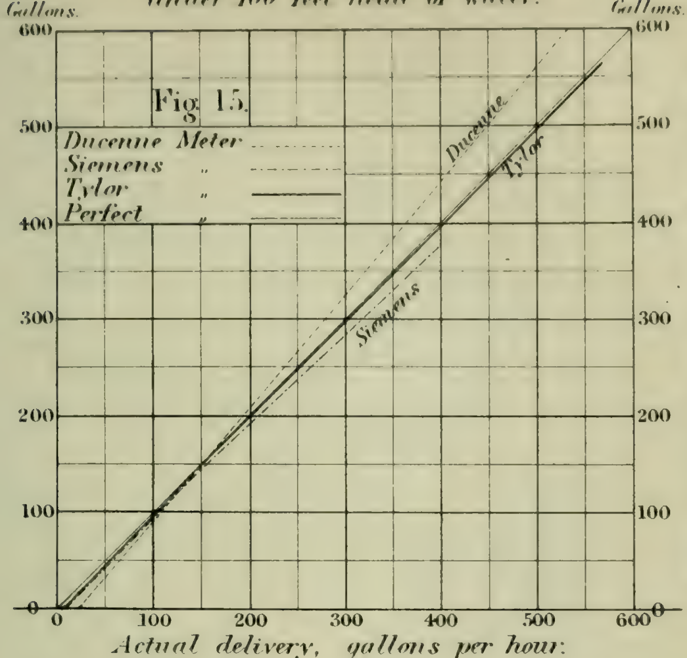


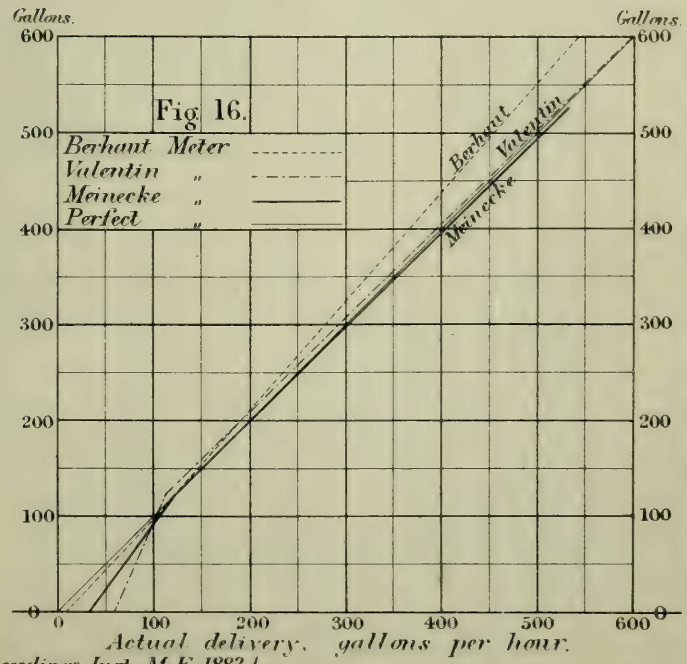
Fig. 14. *District Meter Diagram, Reading, (after inspection).*



The faint figures in brackets are the consumption recorded by the meter in each hour.

Experiments with Water Meters under 100 feet head of water.





(Proceedings Inst. M. E. 1882.)

Galasse Meter.

Fig. 17. *Transverse Section.*

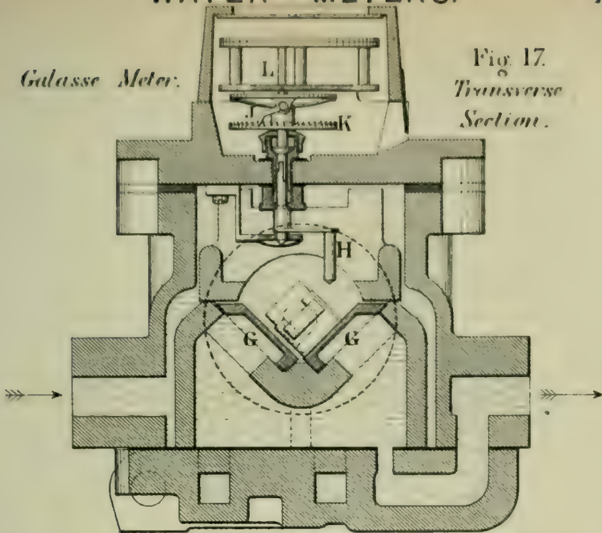


Fig. 18. *Long^l Section.*

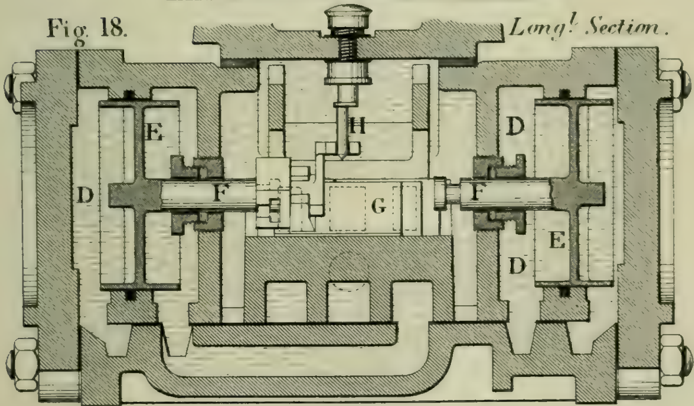
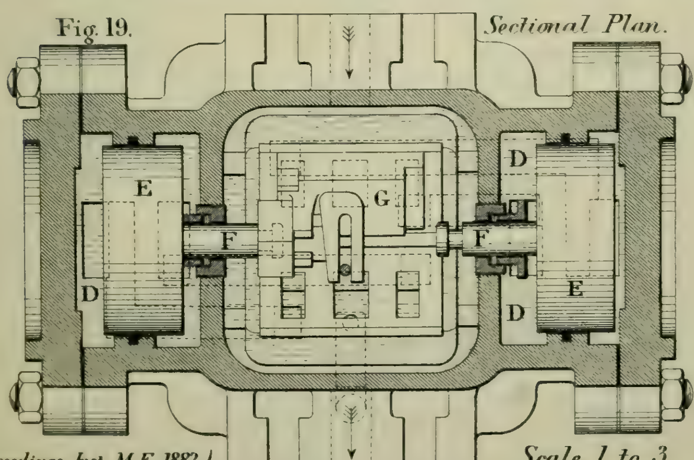


Fig. 19. *Sectional Plan.*



(Proceedings Inst. M.E. 1882.) *Scale 1 to 3.*

WATER METERS.

Diagrams from Deacon Waste-Water Meter.

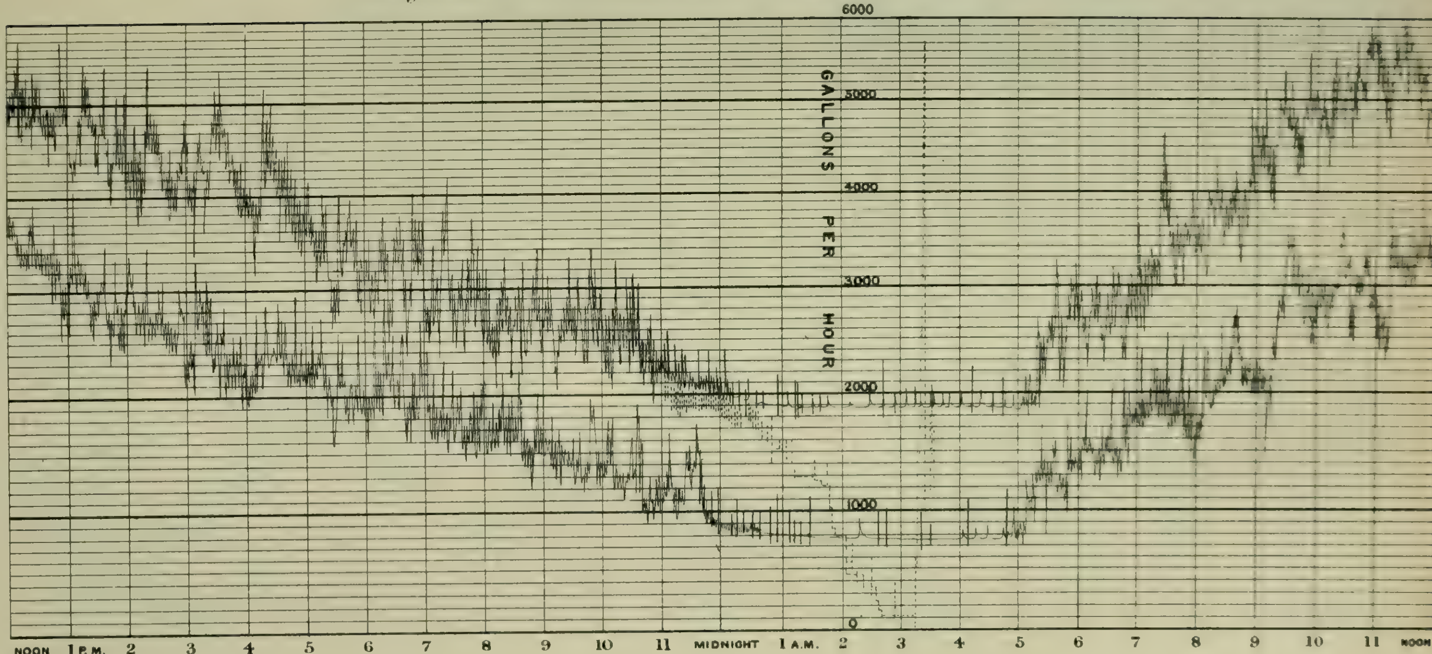


Plate 7.

(Proceedings Inst. M. E. 1882.)

BAZIN DREDGER.

Fig. 1.

Longitudinal Section of Dredger.

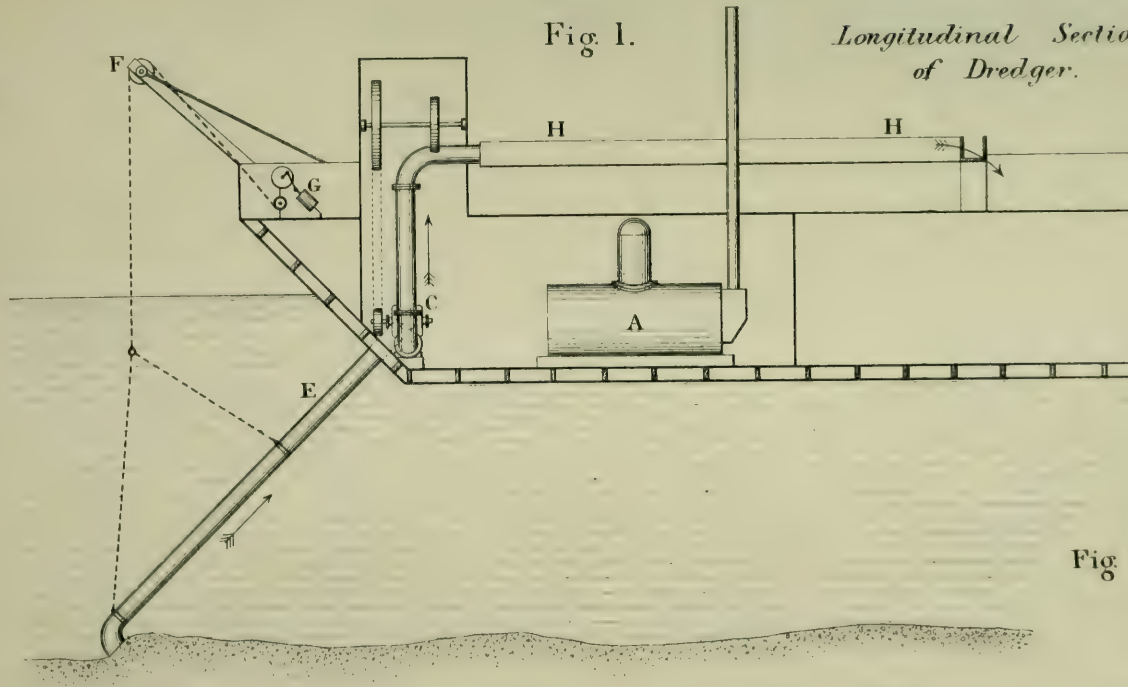


Fig. 2.

Scale 1 to 128

Feet 10 5 0 10 20 30 40 Feet.

(Proceedings Inst. M. E. 1882.)

Plate 8.

BAZIN DREDGER.

Fig. 3.
Transverse Section of Dredger.

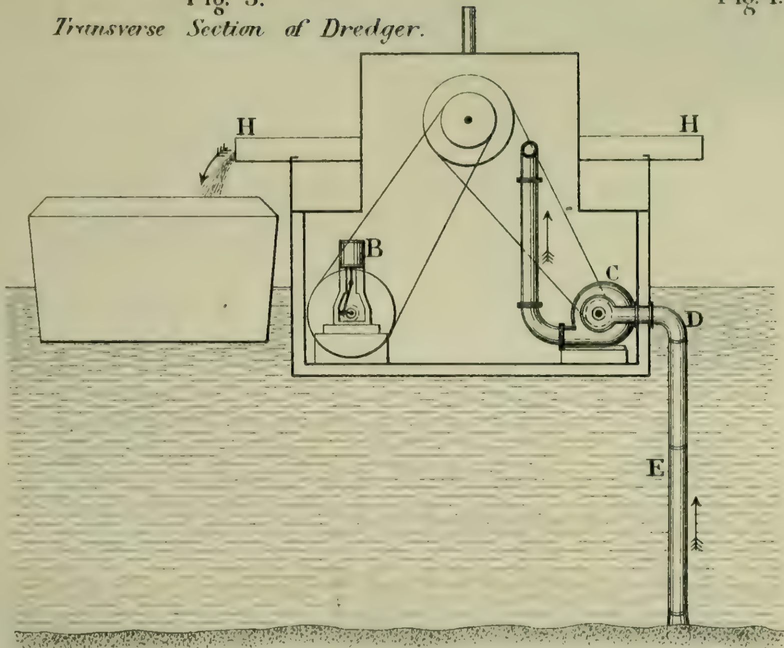


Fig. 4. *Section of Pump through YY.*

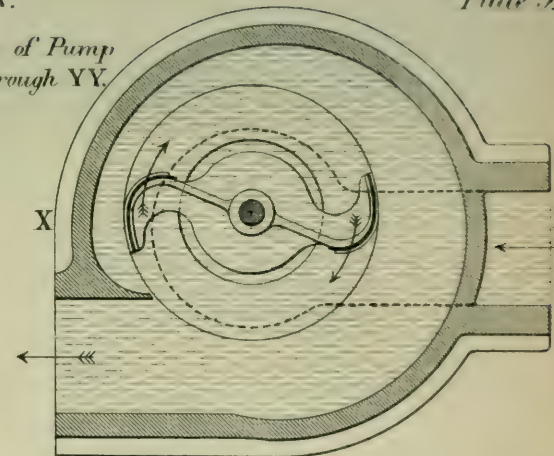
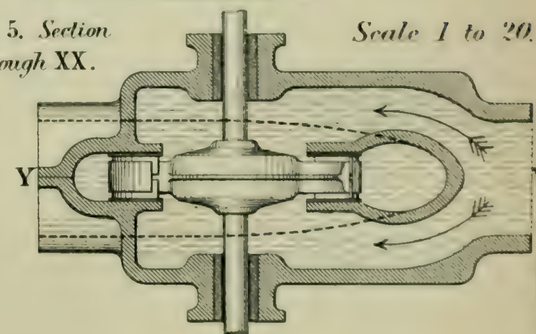


Fig. 5. *Section through XX.*

Scale 1 to 20.



(Proceedings Inst. M E. 1882.)

Scale 1 to 128.

HYDRAULIC LIFTS. *Plate 10.*

Hand Jigger Lift.

Fig. 1.

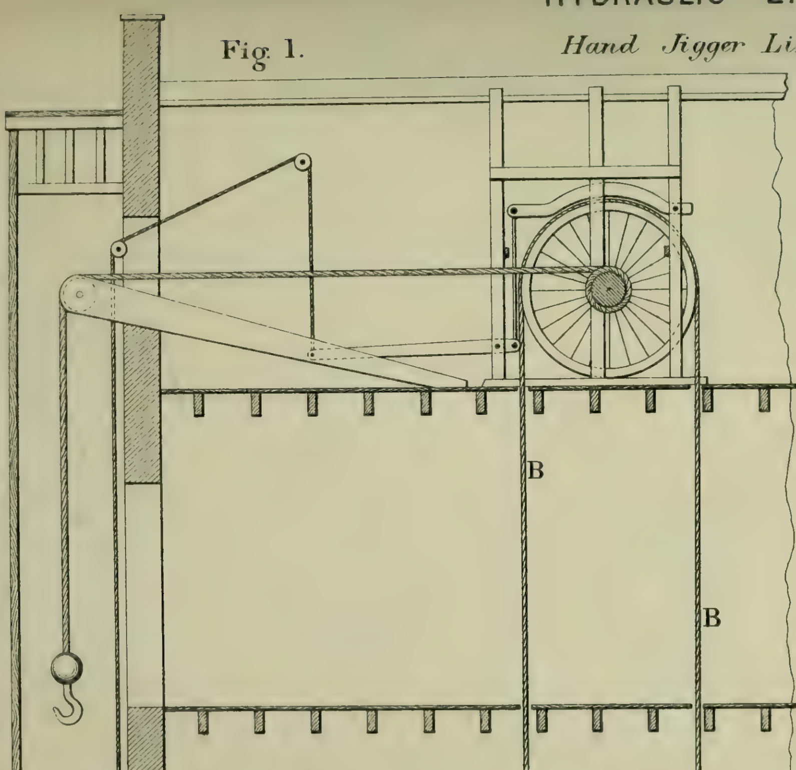
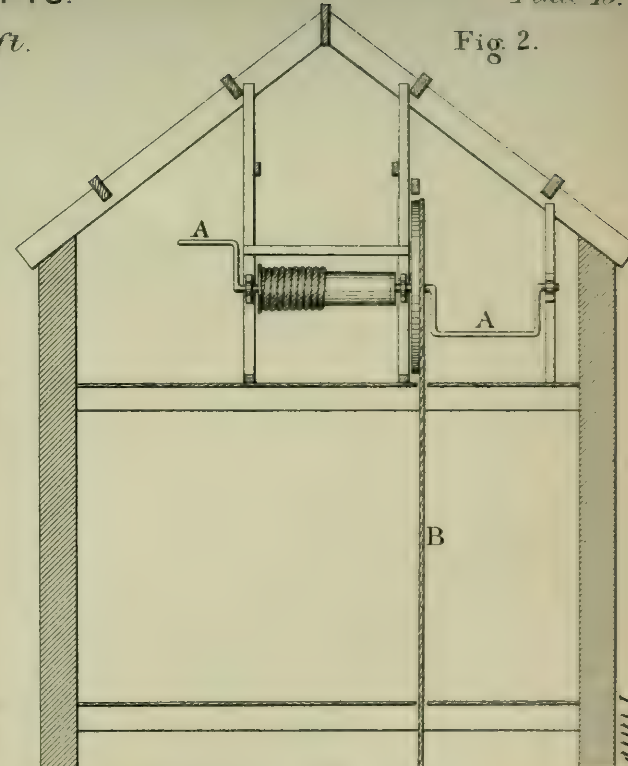


Fig. 2.



(Proceedings Inst. M.E. 1882.)

Scale 1 to 72.

Plate 10.

Hydraulic Jigger Lift, horizontal cylinder.

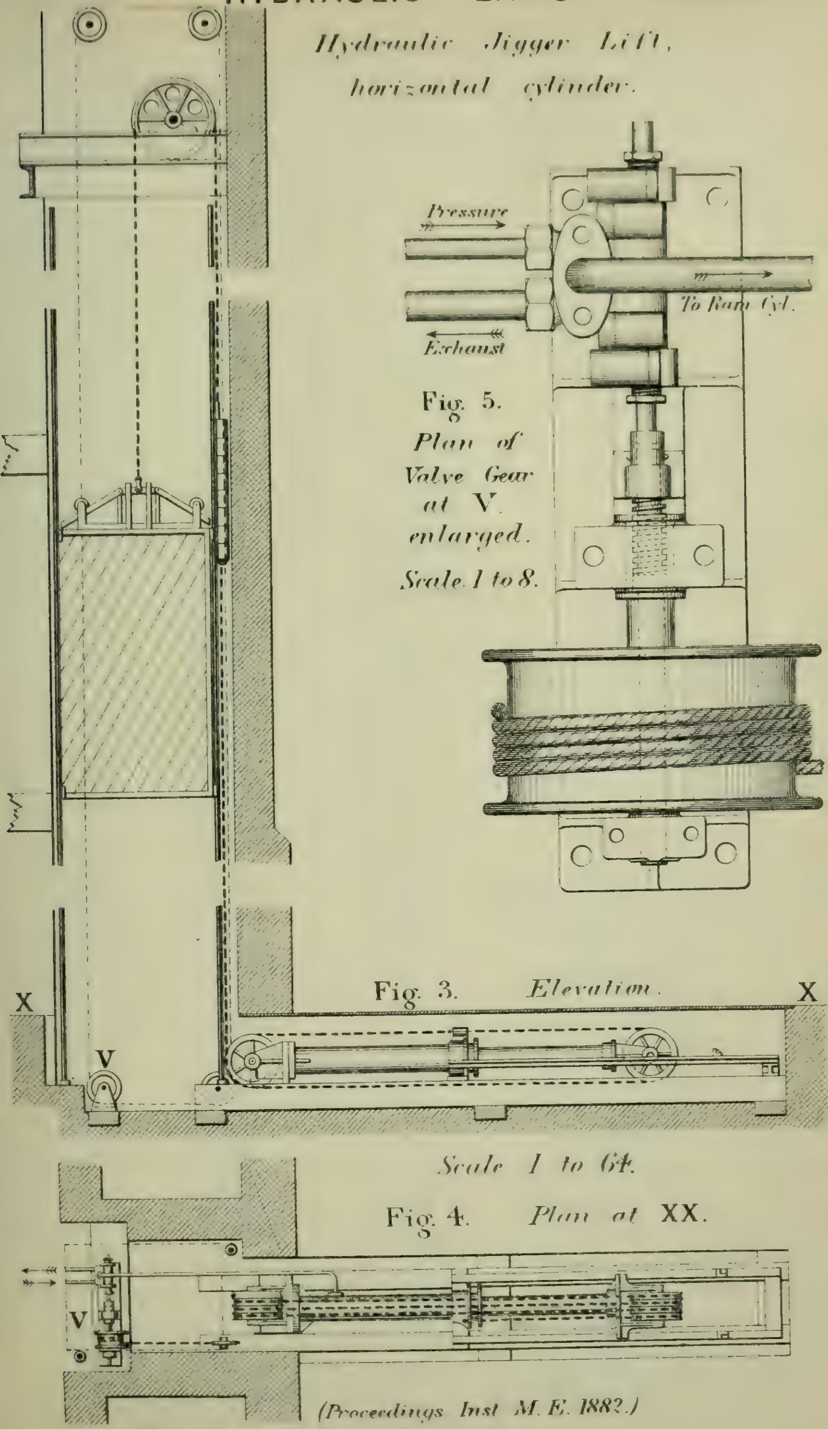


Fig. 5. *Plan of Valve Gear at V. enlarged.*

Scale 1 to 8.

Fig. 3. *Elevation.*

Scale 1 to 64.

Fig. 4. *Plan at* XX.

(Proceedings Inst M. E. 1882.)

HYDRAULIC LIFTS.

Plate 12.

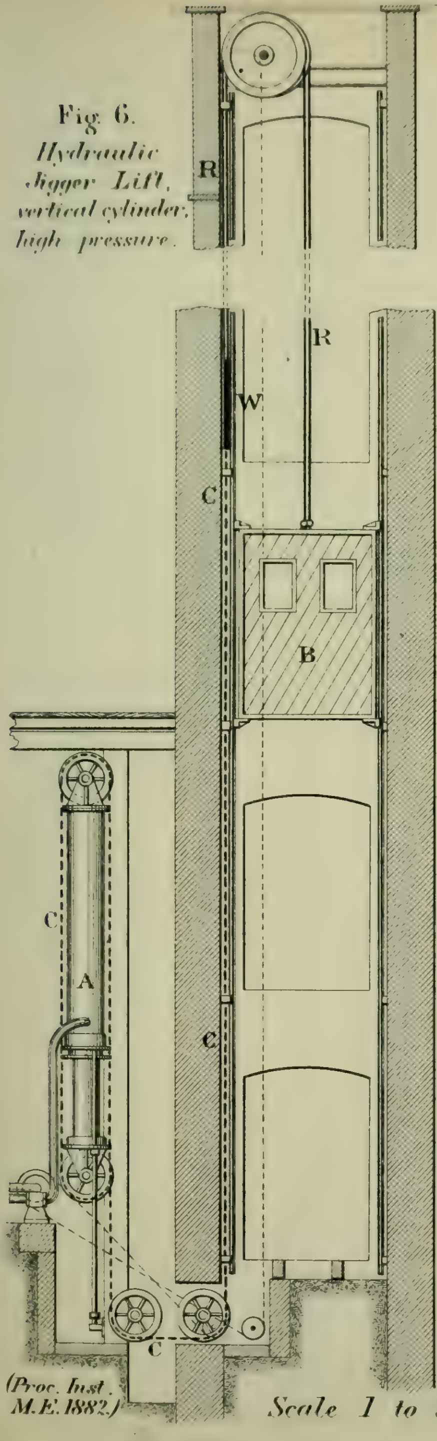


Fig. 6. *Hydraulic Jigger Lift, vertical cylinder, high pressure.*

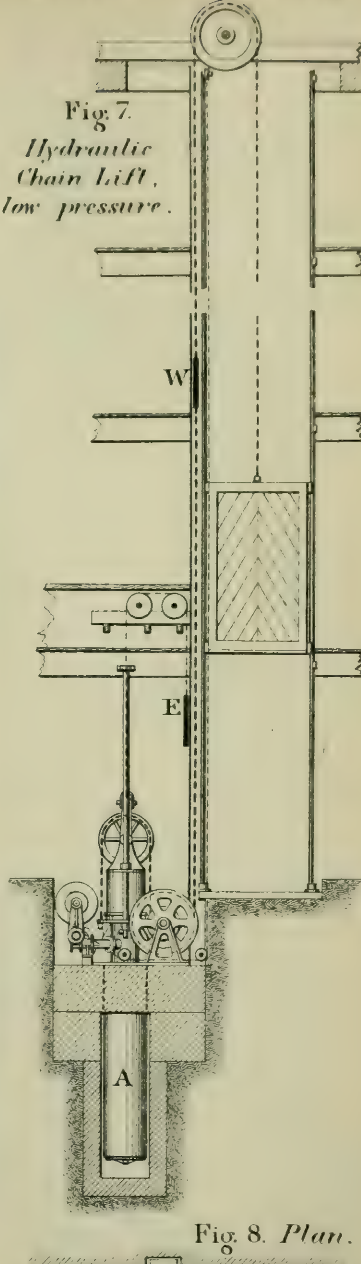


Fig. 7. *Hydraulic Chain Lift, low pressure.*

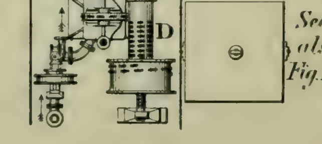


Fig. 8. *Plan.*

See also Fig. 14.

(Proc. Inst. M.E. 1882.)

Scale 1 to 96.

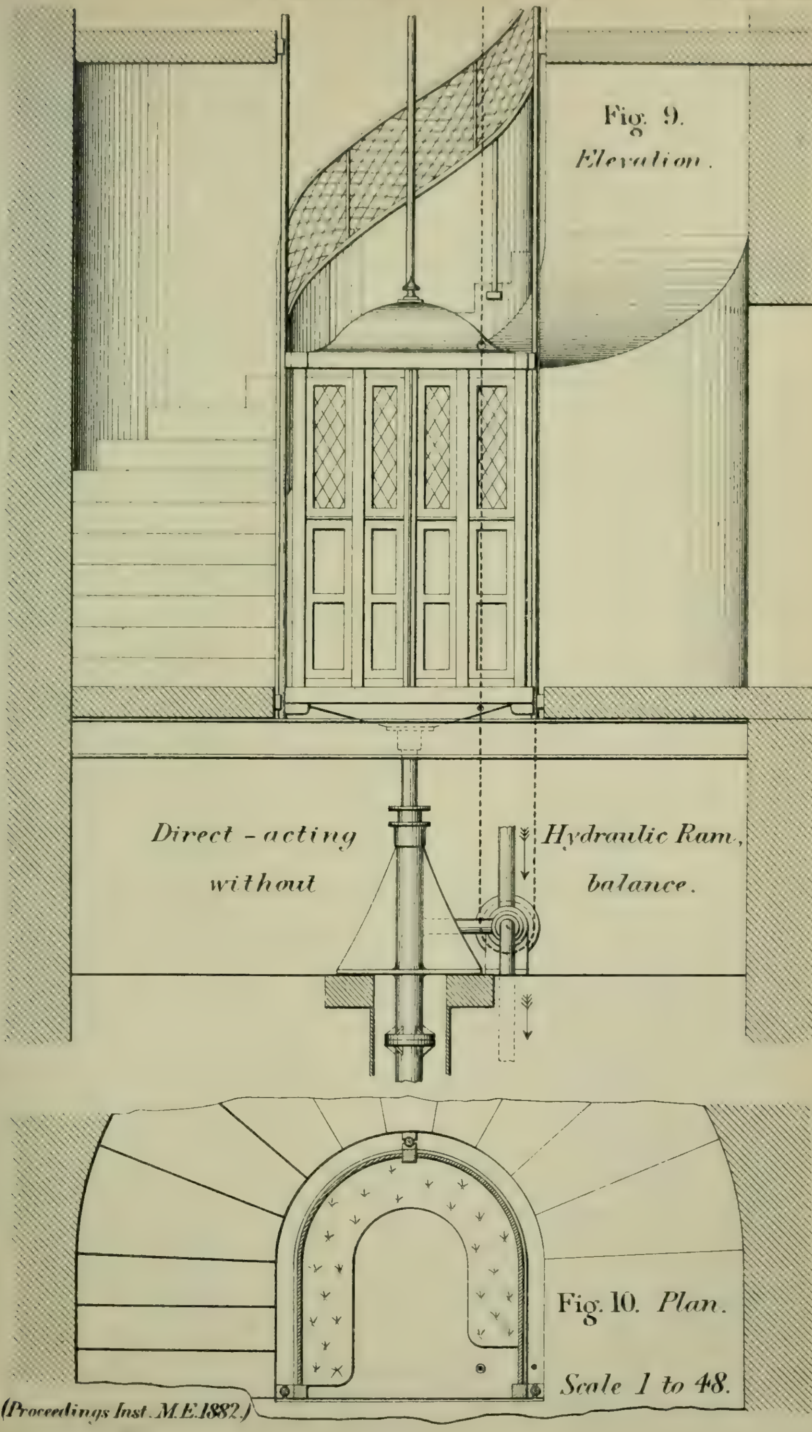
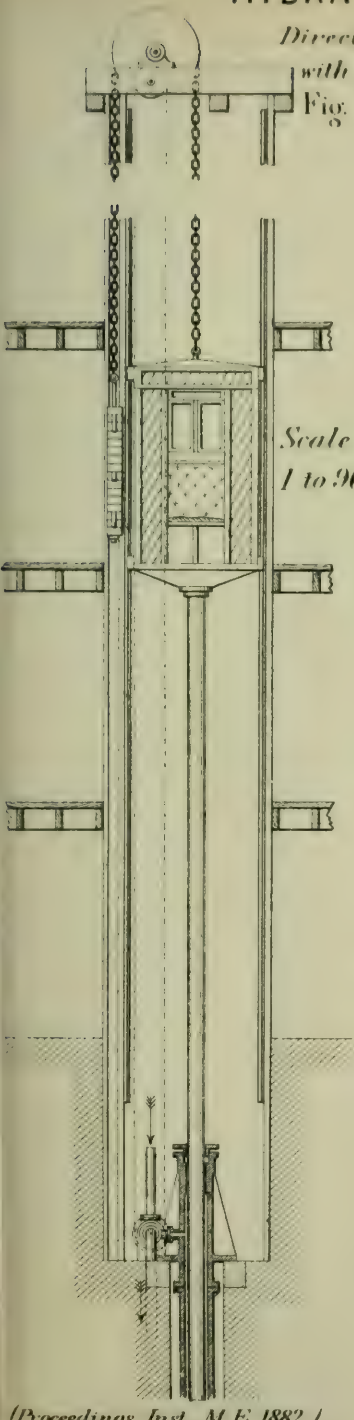


Fig. 9.
Elevation.
Direct-acting Hydraulic Ram,
without balance.
Fig. 10. Plan.
Scale 1 to 48.

HYDRAULIC LIFTS. *Plate 14.*

Direct-acting Hydraulic Ram with counterweight and balance chain.

Fig. 11.



Scale 1 to 96.

Fig. 12.

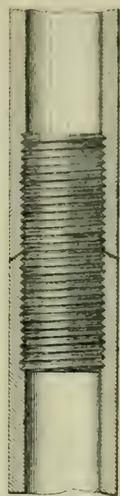
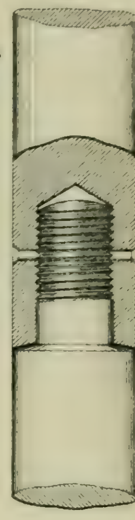


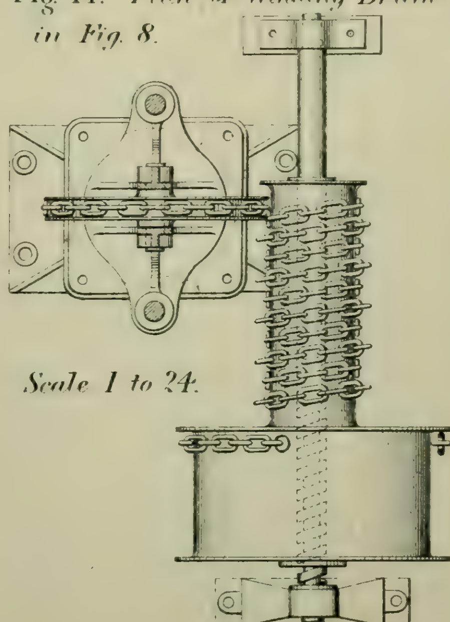
Fig. 13.



Couplings of Hollow and Solid Steel Rams.

Scale 1 to 6.

Fig. 14. *Plan of Winding Drum in Fig. 8.*



Scale 1 to 24.

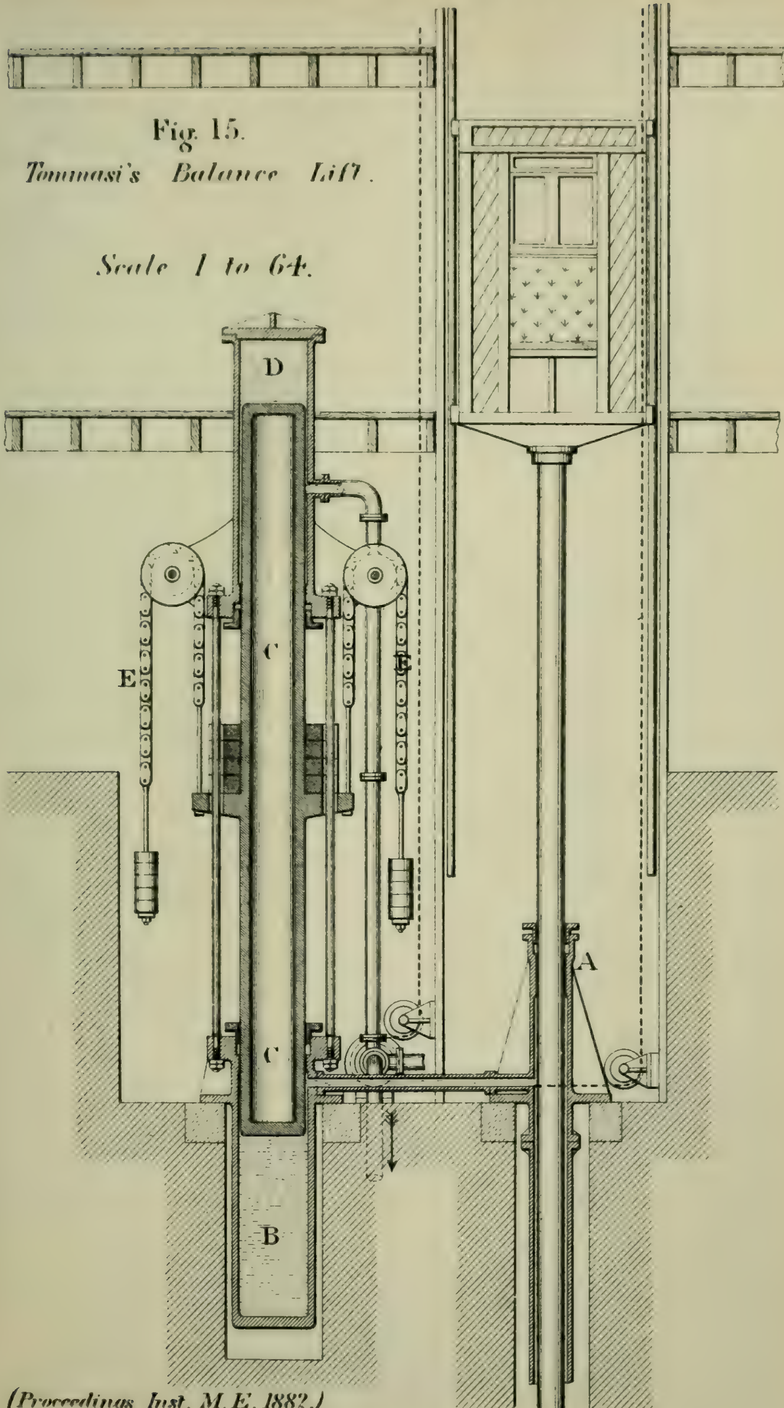


Fig. 15.
Tommasi's Balance Lift.
Scale 1 to 64.
D
C
E
E
C
A
B

Hydraulic Balance Lift, for low pressures.

Fig. 16.
Scale 1 to 96

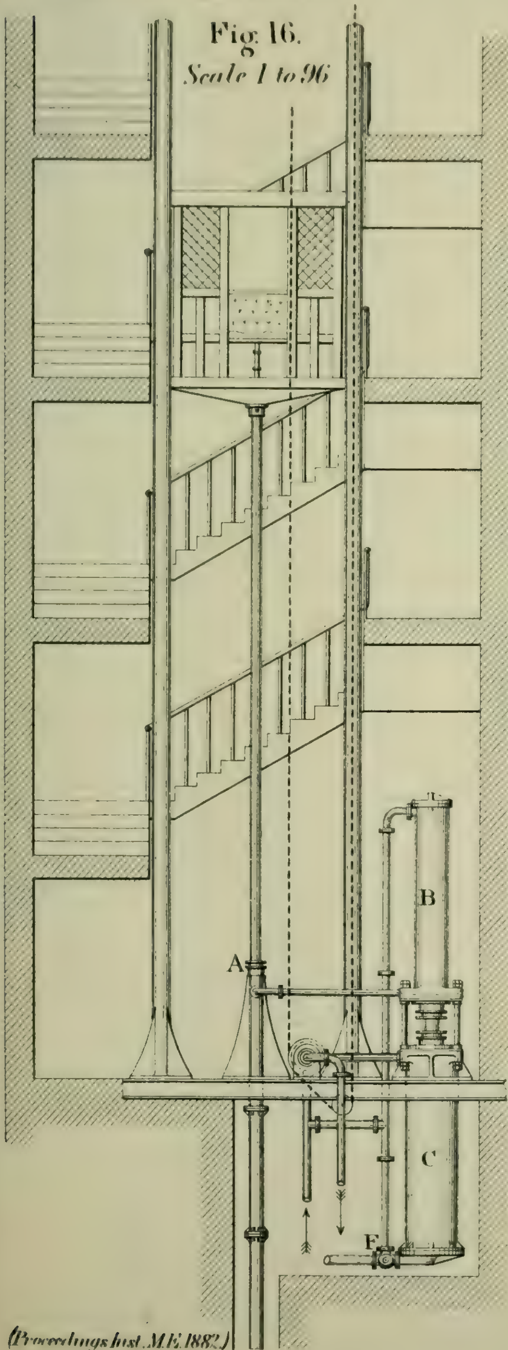
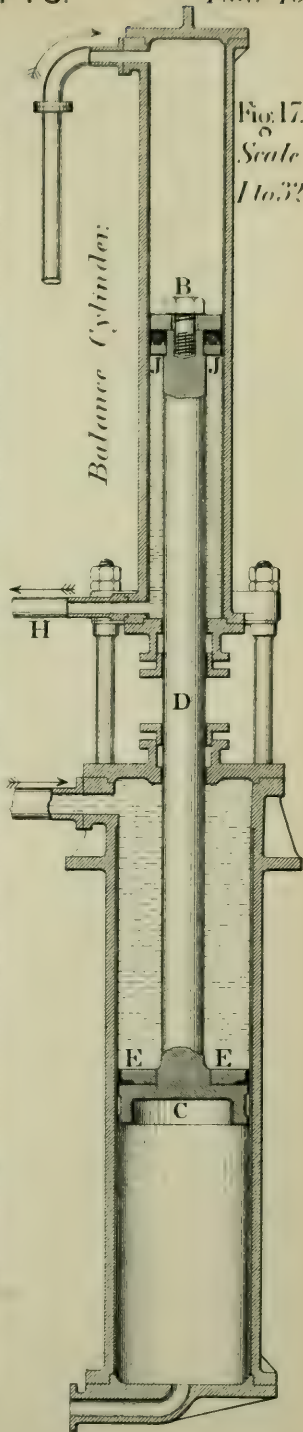
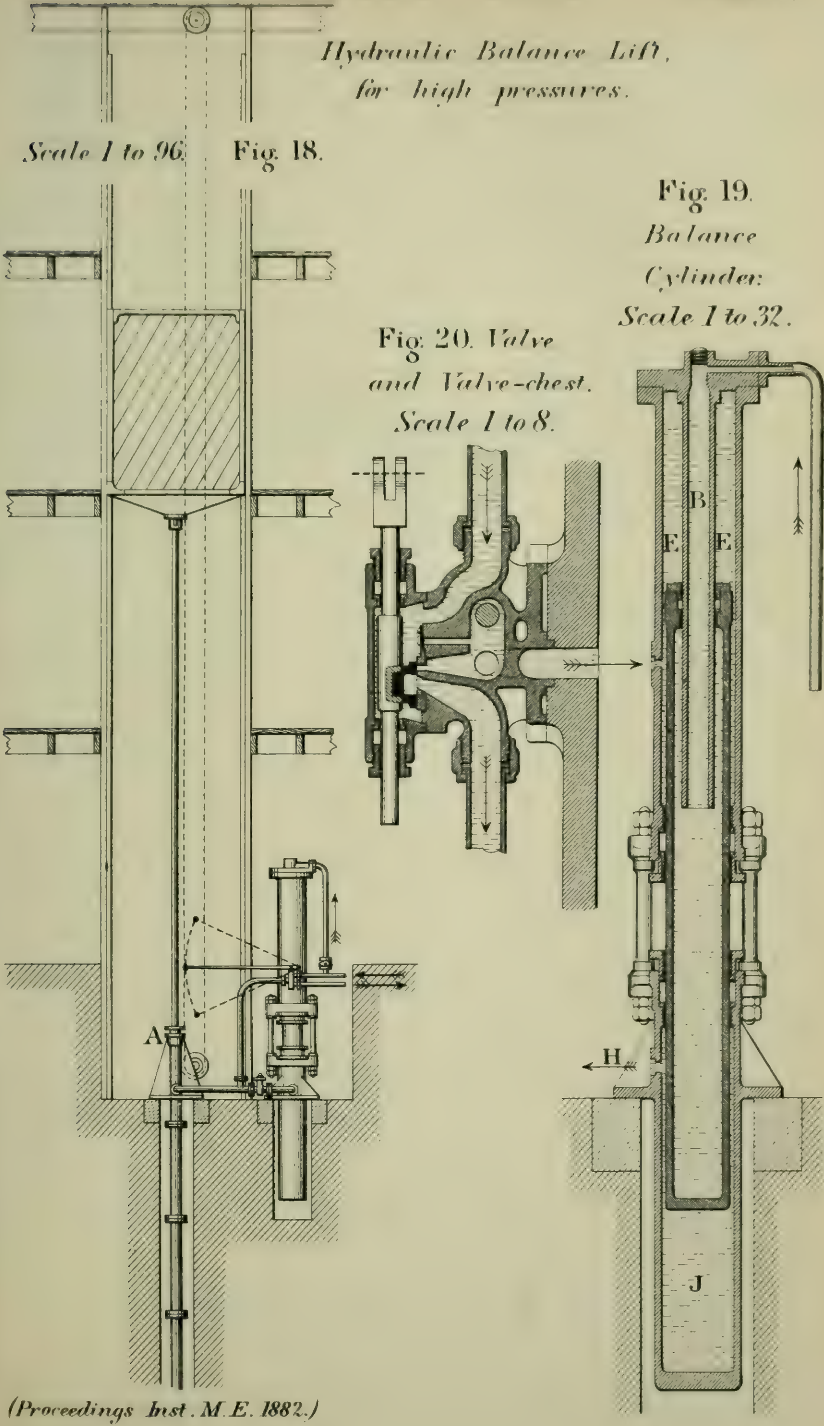


Fig. 17.
Scale 1 to 32.

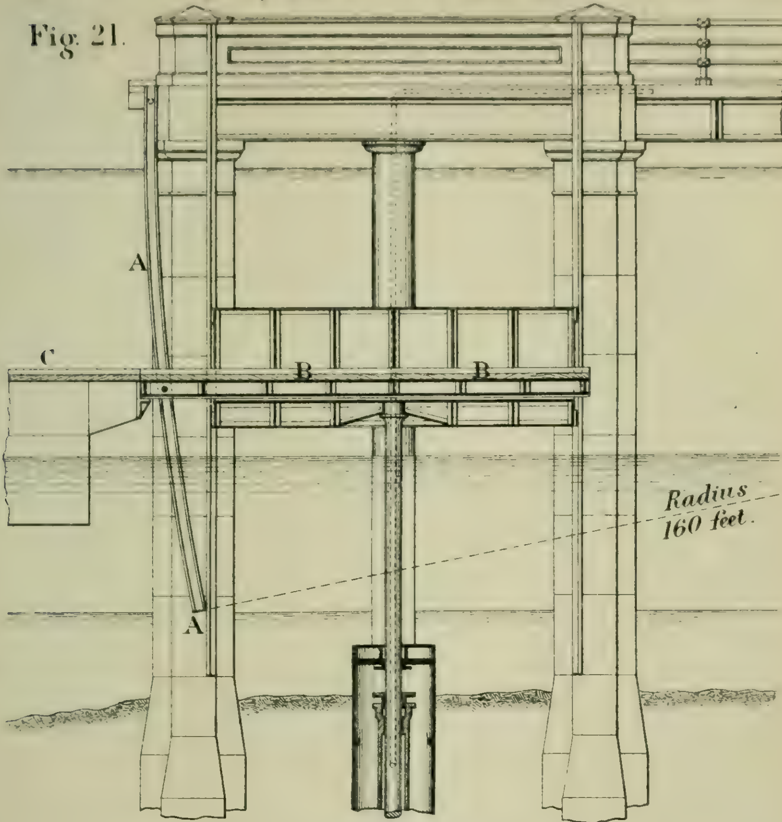


Hydraulic Balance Lift, for high pressures.



Direct-acting Hydraulic Lift at Seacombe Pier.

Fig. 21.



Scale 1 to 144.

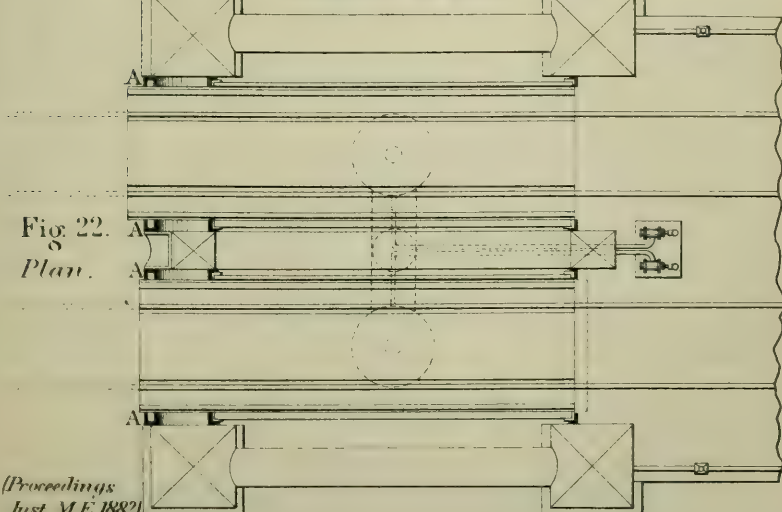
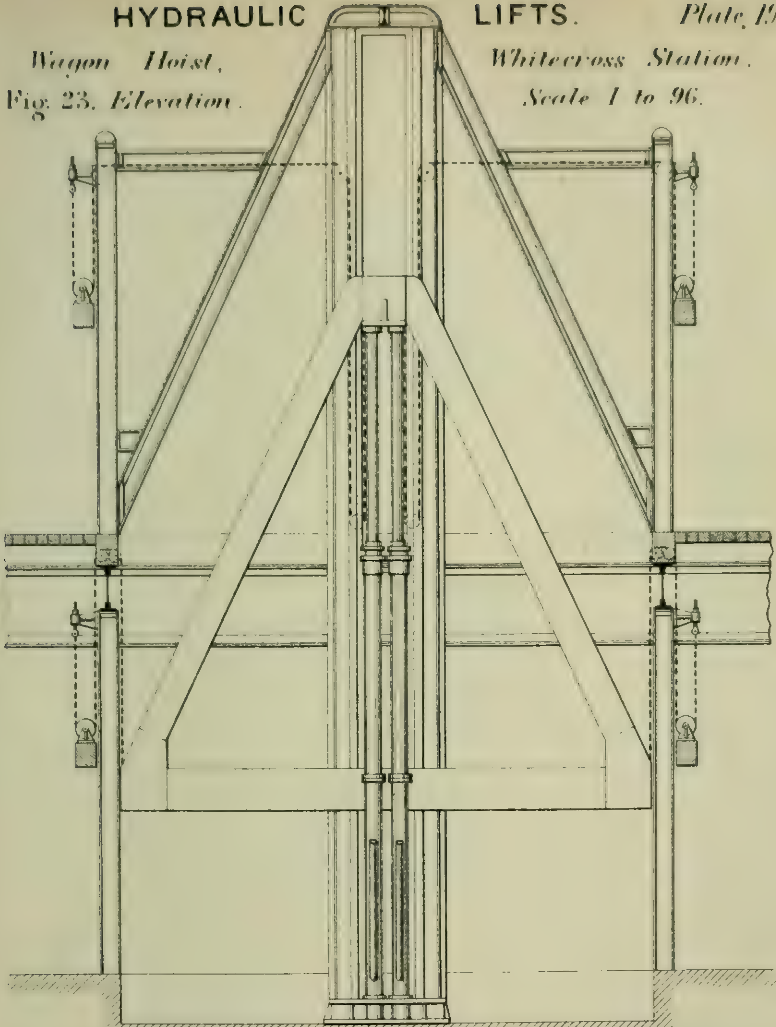


Fig. 22.
Plan.

Wagon Hoist, Whitecross Station.

Fig. 23. *Elevation.* *Scale 1 to 96.*



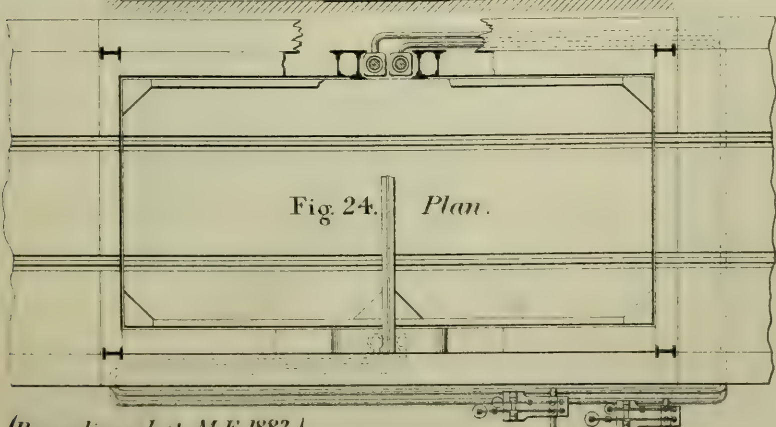
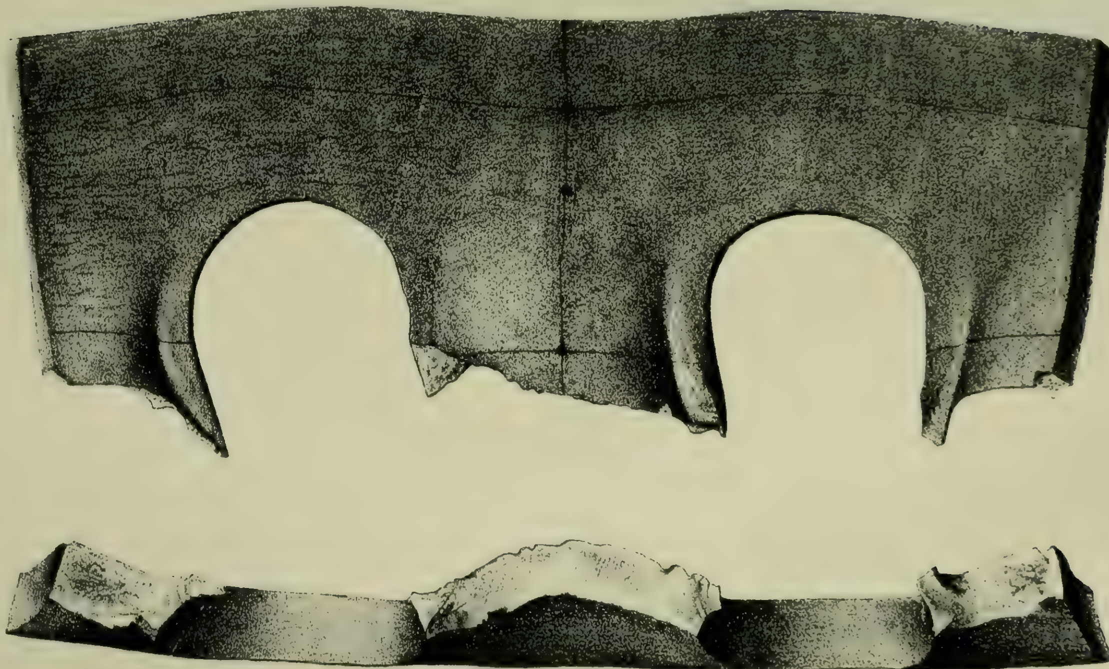


Fig. 24. *Plan.*

RIVETED JOINTS, SERIES X.

Sketch of end after fracture.



(Proceedings Inst. M. E. 1882.)

Full size.

Plate 20

Institution of Mechanical Engineers.

PROCEEDINGS.

April 1882.

The Spring Meeting of the Institution was held at the Institution of Civil Engineers, London, on Thursday, 20th April, 1882, at Three o'clock p.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The Minutes of the last Meeting were read, approved, and signed.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and that the following candidates had been found to be duly elected :—

MEMBERS.

Thomas Arthur Bewley,	Dublin.
Frederic Bradley,	Kidderminster.
Raphael Martinez Campos,	London.
Alfred Joseph Goldsmith,	Queensland.
John Ferguson Haskins,	London.
Henry Hiller,	Manchester.
Edmund Howl,	Tipton.
John George Hudson,	Glasgow.
William Ingham,	Oldham.
John Inglis,	Hong Kong.
Philip Jolin,	London.
Herbert Howard Keeling,	Eltham.
Frederick William Lawson,	Leeds.
Robert Samuel Lloyd,	London.
John Tempest Meats,	Taunton, U.S.

Thomas Nunneley, ...	Leeds.
Frederic Henry Read Sawyer, . .	Manila.
Samuel Lord Sharrock, ...	Chester.
John Tweedy, ...	Newcastle-on-Tyne.
Thomas Henry Ward, ...	Tipton.
Henry Warsop, ...	Nottingham.
Corbet Woodall, ...	London.

ASSOCIATE.

Robert Francis Drury, ...	Sheffield.

GRADUATES.

William Anderson, ...	York.
Raynes Lauder McLaren, . . .	London.
Hugh Nettlefold, ...	Birmingham.
Juan Emilio Sanchez, ...	London.
George Herbert Wailes, ...	London.

The President said the adjourned discussion was now open upon the Reports as to the Hardening &c. of Steel, and as to Riveted Joints, published in the recent Nos. of the Proceedings.

Mr. William Anderson said that, with regard to Steel, Professors Abel, Chandler Roberts, and Williamson were still at work, he believed, in making experiments, but they were hardly yet in a position to draw any conclusions from them; he therefore thought it would not answer any good purpose to start a discussion upon the subject at present.

Mr. W. H. Dugard said in the year 1875 Professor Norris, of Queen's College, Birmingham, had made a series of experiments to ascertain the effects produced upon steel and iron wire by the processes of hardening, tempering, and annealing. He embodied the results of his researches in a paper, which he communicated to the Royal Society in 1877, and to an abstract of which reference was made

in the First Report of the Committee (Proc. Inst. M. E. 1881, p. 690). The paper was still in the archives of the Society, but the diagrams in connection with it had been returned to Prof. Norris, who had kindly allowed him to bring them to London with him, where they could be seen at the offices of the Institution. There were fifty-one diagrams, showing the results of about one thousand experiments connected with the hardening, tempering, and annealing of steel wires, and showing very clearly the curious phenomena of "kicks," or contractions during heating and expansions during cooling, which were described in Prof. Norris's paper.

Professor Abel, C.B., F.R.S., was sorry he had nothing to add in the way of new facts to those that had been already laid before the Institution in the Reports of the Committee on the Hardening &c. of Steel, in which certain experiments carried on under his direction had been embodied. It was his hope that, in the course of the present year, he should be enabled to carry on still further those researches, which had been commenced with considerable promise of success. Unfortunately his many official occupations had prevented his re-entering upon the subject hitherto; but some further steps had been taken by his communicating with Mr. Paget, who had promised to prepare a series of specimens, the specification for which had been determined by the results previously obtained. He had already received from Mr. Paget a comparatively large specimen of thin sheet steel, or steel foil—he presumed with about 1 per cent. carbon; and this he purposed treating with the special object of examining as thoroughly as possible the carbon and iron compound, which, as he had pointed out, was separated in considerable quantity from the different samples of steel he had tried, and which, in the case of annealed steel, appeared to contain practically the whole of the carbon originally in the metal. He hoped to obtain more perfect information with regard to the precise composition of that carbide, and with regard to the manner in which it behaved under different circumstances. Probably by that examination of the carbide they would obtain hints as to the direction in which it was desirable to pursue the experiments further.

Mr. Paget was also preparing a series of specimens, having for their object to determine thoroughly the difference, in regard to percentages of carbon, between samples of steel that had been annealed or hardened by different processes; and also to determine with more precision how far the separation of the carbide in different proportions was an indication of different temper in the steel.

He could not close his remarks without referring to an interesting little work, published by Messrs. Miller Metcalf and Parkin, of the Crescent Steel Works, Pittsburgh, U.S., and entitled "The Treatment of Steel." It included a paper of special interest entitled, "Why does steel harden?" In it the authors discussed mainly the question of the variation in the specific gravity of different samples of steel; and they had arrived at one or two interesting results. That the specific gravity was reduced in direct proportion to the increase in percentage of carbon in the steel was what might have been anticipated, and also that the other elements, existing in comparatively small proportions, exerted a comparatively small influence on the specific gravity; but a point of some interest was that the quenching of the metal from different temperatures—in other words the heat of the metal at the moment previous to quenching—appeared to have a decided influence upon the specific gravity after hardening. In proportion as metal of a particular composition was hardened, so its specific gravity was reduced. But the most interesting observation was that, judging at least from the influence on the specific gravity of the sample, a specimen of steel which had been simply heated to about the temperature of boiling water, and then quenched, was decidedly hardened. It appeared that a gentleman who worked in conjunction with Messrs. Miller Metcalf and Parkin—Prof. Langley,—with the view of removing the scale from some samples of steel, had heated them for a short time to boiling point in an alkaline solution, and then plunged them suddenly in cold water; and he found that the specific gravity of the samples was decidedly reduced. He carried his experiments further with other specimens, and found the result to be pretty uniformly maintained: so that it would appear that the mere heating of the metal to a temperature of about 212° Fahr. (or 100° Cent.), and then quenching, was sufficient to have a hardening influence

upon it—judging at least from the specific gravity only. Whether that would be actually established by critical examination of the samples with reference to their hardness remained to be seen; but it was an interesting observation, and an indication that an examination of specific gravities, if pursued further, might probably lead to very interesting results in connection with the variations in the tempering and character of steel.

Mr. A. Paget, referring to the set of samples alluded to by Prof. Abel, said there had been some delay in their preparation, in consequence of Prof. Abel's very proper desire to have them all of one material. It would be seen from Prof. Abel's report (Proc. 1881, p. 698) that in one of the samples of steel, which had been annealed between wrought-iron plates, a large proportion of the carbon seemed to have gone out of the steel, and had probably passed into the wrought-iron plates. It was desirable to check this by renewed experiments with plates known to be of the same material; and in the course of a week a further and complete set of such samples would be sent to Prof. Abel. It was only right to add that the gentleman who had put them upon the right track in finding out the cause of this deficiency in carbon, which had puzzled Prof. Abel and himself,—namely that the steel had been annealed between wrought-iron plates—was Mr. W. H. Maw. The present samples were being annealed with great care, some of them taking thirty-six hours in the process of cooling; and he thought that the result would satisfactorily prove that the carbon did pass from the plate of steel into the plates of wrought iron.

Mr. W. W. Hulse said if he was not out of order he should like to ask what progress was being made by the Research Committee on the question of Friction at different surface velocities. The subject—including as it did the friction of revolving shafts, the safe and the unsafe load per square inch to put on the bearings at various velocities, with various materials, and with various lubricants; and also the question of the friction of worm gear as compared with other gearing—was an interesting and important one to the Institution, and was anxiously awaited.

The President said a gentleman had that day been appointed, who was in every way admirably fitted to carry out the experiments proposed by the Committee, and who would soon be in a position to take the subject in hand.

The adjourned discussion on Mr. Ellington's paper on Hydraulic Lifts for Passengers and Goods then took place.

On the motion of the President, a vote of thanks was unanimously passed to Mr. Ellington for his paper.

The following paper was then read and discussed:—

On improved Appliances for Working under Water, or in Irrespirable Gases; by Mr. W. A. Gorman, of London.

At 6 p.m. the Meeting was adjourned to the following day. In the evening the Annual Dinner of the Institution was held at the Criterion Restaurant, Piccadilly.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, 21st April, 1882, at Three o'clock p.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The discussion upon Mr. Gorman's paper was resumed, and concluded.

The President proposed a vote of thanks to Mr. Gorman for his paper and specimens of diving appliances; and also to Mr. Fleuss for the exhibition and explanation of his breathing apparatus and lamp.

The following papers were then read and discussed :—

On Power Hammers with a Movable Fulcrum; by Mr. Daniel Longworth, of London.

On Wool-Combing by Modern Machinery; by Mr. F. M. T. Lange, of Amiens.

On Machinery for the Sowing of Seed; by Mr. James J. Smyth, of Peasenhall.

On the motion of the President, votes of thanks were unanimously accorded to the authors of the papers.

The President reminded the Members that the Summer Meeting of the Institution, to be held in Leeds as already announced, would commence on Tuesday, 15th August.

On the motion of the President, a vote of thanks was carried by acclamation to the Institution of Civil Engineers, for their kindness in granting their rooms for the use of the Institution.

The Meeting then terminated.

Abstract of Discussion on Hydraulic Lifts.

Mr. BENJAMIN WALKER said that, with the author's general conclusion—that the hydraulic direct lift was the best and the safest—he entirely agreed; but with his criticisms on some of the systems of hydraulic lifts he did not agree. For example, the author had stated, p. 120, that the ordinary safety apparatus, designed in case of a chain breaking to prevent the hoist from falling to the bottom of the well, was not to be trusted. He had known many instances in which the life of a workman had been saved by the safety apparatus, and if that was done in one case, it was likely to be done in many others. He thought such apparatus was quite capable of being made safe; and if so, to give it up as being liable to lead to danger was, in his opinion, not a very wise step. The guides of the hoists used in grain and other warehouses were very firmly and substantially made, and were very different from the guides of the winding cages at a colliery. So far as a colliery was concerned, he agreed with Mr. Ellington that an efficient safety apparatus was a very difficult matter to provide; but when there were reasonably firm and substantial guides, it was very easy so to construct the apparatus that any shock on the descent of the cage would be so far reduced as to do no damage.

The author had spoken on p. 121 of worm gear, and had pointed out that, although there might be complete safety from the use of worm gear, there was a considerable amount of friction and loss of power. But the worm, when properly applied, was a most valuable and useful mechanical contrivance. If indeed the worm had a large amount of friction—say the same as the friction on an ordinary toothed wheel—then the worm and worm-wheel were very wasteful of power; but if the worm was allowed to run at a considerable speed, and the friction was somewhat less than half the friction that would occur with an ordinary toothed wheel, other circumstances being the same, then it would be found that the loss of power was not considerable, while there was great safety arising from its use in many cases, such as cranes or lifts.

The author further remarked, p. 121, that if a hoist was driven by a belt, that was a great source of danger. He might mention that he had put up a hoist fifty years ago worked by a belt, and that it was working still, and he believed during all that time not a single accident had taken place. It was in a very high shaft in a tall flax mill, and there were hundreds of such hoists at work, driven by a straight and crossed belt. With regard to the use of the gas engine, he thought that, in connection with a single direct lift, a gas engine driving a hydraulic pump, or three or four pumps, was a very valuable means of getting a safe and useful passenger hoist.

The form of chain shown at EE in Fig. 15, Plate 15, though not mentioned in the paper, was a very valuable one—he meant a chain of plain links fastened with plain pins. The common chain was constructed of a large number of pieces of iron that were welded under great difficulties, and it was a most wasteful arrangement of material to carry a load. But if you took plain thin plates of steel, cut from a long bar that had been tested, drilled or punched them, and fitted steel pins into them, you got a chain that was practically as safe as a hydraulic cylinder; for hydraulic cylinders did burst, and hydraulic joints did blow out. If that kind of chain were applied to a hoist, and the unbalanced weight of the cage &c. were just enough to make it descend slowly and not fall down, a very efficient hoist would be obtained, and one much less complicated than that shown in Fig. 15. The ordinary Armstrong jigger, if so arranged that it could be raised and lowered by a pitch-chain without having to wind the chain on a drum, formed a remarkably safe hoist; and he would just as soon travel in such a hoist as in the hydraulic balance hoist that had been brought before them. With regard to the instance mentioned, p. 127, where the cage became disengaged from the ram, that was not an error in the principle, but a mere accident of construction. If engineers used pitch-chains carefully constructed, they would find that the accidents from breakage of the chain would be reduced in a still greater proportion than the accidents on railways had been reduced by the change from the old welded iron tyre to the solid-drawn steel tyre.

Mr. F. Colyer agreed with part of Mr. Ellington's statements; but there were several things in which he could not agree with him. It was stated, p. 119, that the safest and best form for passenger lifts should also be adopted where practicable for goods, because workmen were often allowed to travel in those lifts. He would rather say that workmen should never be allowed to travel in an ordinary chain lift. Experience had taught him that, even with the best class of safety apparatus, it was very difficult to make such lifts absolutely safe. With regard to safety apparatus, as applied for the purpose of goods lifts alone, he had found a modification of the arrangement introduced first, he believed, by Sir Wm. Armstrong & Co.—a kind of cam and toothed rack, attached to the top of the cage and clipping the guide timbers—to answer perfectly well. Some years ago, through the courtesy of some of the largest Manchester firms, he had been allowed to see the safety apparatus they had in use, and he had found most of them very faulty. He had then examined many of those catches made by Sir Wm. Armstrong & Co., and from them he got the idea of an apparatus which he subsequently designed and used. In several instances the lifting rope had been wilfully cut by some one, in a fast-running lift, ascending at the rate of 200 to 250 feet per minute, and the total fall of the cage when the rope broke was only 3 inches. He thought that fact showed it was a good safety apparatus; and he knew a great number were in use at the present time. On one particular occasion when the rope broke in ascending, the fall being about the same, one of the gentlemen in the lift, who had been much frightened, said he had fallen 14 ft.; but the catches by measurement showed exactly the amount it had really fallen. Every one had been frightened, and as usual the lift was much overloaded. That occurred about ten or twelve years ago; he had used the apparatus constantly in goods lifts ever since, and had never known it to fail.

It was remarked, p. 120, that if wire ropes were used, two should be employed. If two were used, great care must be taken to ensure that each rope should take the same amount of tension; otherwise, if one rope was tight and the other slack, when the tight rope broke, the shock thrown upon the other might be sufficient to break it.

He agreed with what was said as to the attachments between the chains and the cage, because, in the numerous cases of accidents which he had been called to examine into, he had more often found that it was the attachment that was faulty than the chain. Therefore he always had attachments made expressly for the purpose, of the best kind, and made stronger in proportion than the chain.

It was stated, p. 121, that there was a great loss in lowering by steam, when using steam lifts. With that he could not agree. The loss in lowering by steam was very small. The most efficient steam hoist that he knew of, where all the operations were done by steam—raising, lowering, and braking—was one having a special valve-box, which he had used for some years, and having only one lever to control the whole operation. The valve-box was placed between the cylinders, and the steam admitted at the top or bottom of the pistons as required. The advantage was that the man working the hoist had the most perfect power over the apparatus, and could always easily control it. There were no clutches to throw in and out, and no brake to put on; consequently the wearing parts were reduced to a minimum. Mr. Ellington also said that with steam lifts there was a considerable danger of accident from overwinding. He did not propose to go into the question of colliery lifts, because that was a different matter; but overwinding in ordinary warehouse lifts, worked by steam, could be avoided. He was constantly using lifts for goods, running at 250 and 300 ft. a minute, and he used gear by which the lifting power would be thrown out of action at the top of the stroke. When the cage ran at that speed, its fall, with the safety-catch described, would not be more than 3 to 5 in.

At page 122 reference was made to the best general form of hydraulic-power chain-hoists. It was only fair to mention, as the author did, that Sir Wm. Armstrong and Co. were the first to bring out a lift in that particular form; and in his own opinion nearly all the hydraulic short-stroke cylinders used to the present time had been constructed on that idea. It was therefore to Sir Wm. Armstrong that the sole credit of producing that class of apparatus belonged. It was stated, p. 123, that in these short-stroke lifts there was a certain danger, if the cage were too nearly balanced, because

there was a chance of the cage sticking and the chain running off the pulley at top, and leaving the cage free to fall subsequently. That danger however could be entirely avoided by winding off as you wound on—using a large drum below, and winding off from the bottom of the cage as you were winding on from the top. The cage could thus be balanced within a few pounds of its weight, and would be always safe. This plan was designed by himself, and had always worked perfectly. With regard to the winding drums, in such cases his experience had been that they should be made large, and that wire ropes should never pass over a pulley of less diameter than from 14 to 18 inches, and should be taken as direct as possible from the top pulley to the drum, without passing over leading pulleys; otherwise by the constant bending of the rope in different directions it became brittle, and at last broke suddenly.

It was remarked, p. 126, that with direct-acting ram lifts there was a limit to the height at which they could be used. Practically however there was no limit, as far as the ordinary buildings in London and elsewhere were concerned. The height of a hotel or other building where a hoist was used certainly would not exceed 90 or 100 feet; and an ordinary ram and cage could be raised 100 feet with the greatest ease. If a lift were needed for a greater height,—as at Queen Anne's Mansions, Westminster, where he believed one was at work, made by Messrs. Easton and Anderson,—it was easy to provide a second lift, starting from the level where the other ended. In that way there was practically no limit to the height that could be worked. As to danger from the use of counterweights and chains, p. 126, he maintained that when an apparatus of this kind was properly designed there was no such danger as stated. The varying strain upon the ram, described by the author, was a matter of theory rather than of actual practice. No case had ever occurred in this country, to his knowledge, where, in a well constructed hydraulic lift with continuous ram, an accident had taken place through the ram breaking away from the cage. He had seen the lift at the Grand Hotel, Paris, just after the accident, and was not much surprised that it had taken place, as the construction, especially at that part, was very faulty—a remark

which applied to a great many of the French lifts. A fault in many hydraulic lifts was that of attaching the counterbalance chain to the centre of the cage. That should never be done; it was a very dangerous practice. In his designs there were two chains, attached to the sides of the cage by jaws riveted to the side suspending irons; and the chains and counterbalance weights passed down grooves in the wall at each side; there was thus no gear whatever overhead, and no accident could arise from that cause. In addition to this the top of the cage was made, as was usual, of $\frac{1}{4}$ in. boiler-plate, so that, if there was a fall of any heavy weight from any of the floors, the passengers were still safe inside the cage. He did not agree that there was necessarily any danger in using lifts of that kind, and he was borne out in this statement by the large number of such lifts that had been in use for many years without any accident occurring. With his own experience of over fifteen years, he could point to a large number of hydraulic ram lifts worked by counterbalances, which were in constant use, on which there had scarcely been any repairs, and with which certainly no accident had ever occurred.

The author's own design, p. 128, he could not think a very good one, because it comprised the addition of a very complicated apparatus, very liable to get out of order, and very likely to fail at a critical moment. According to his own experience, simplicity of design should be the first consideration in all such cases; and that certainly would not be obtained by the addition to the original machinery of such complicated apparatus as was proposed by the author. It was stated, p. 130, that hydraulic passenger lifts *could* be run at a speed of 200 ft. per minute. Of course high-pressure lifts might be run at almost any speed; but he thought it would be objectionable to run a lift at such a speed as 200 ft. per minute, as it only frightened the public and prevented many from using the lifts. He did not think it was really safe to work at more than 100 or 150 ft. per minute. It was also stated, p. 131, that there ought to be doors to the cage; but in his opinion they were rather an element of danger than of safety, since in nine cases out of ten they were never closed. As to its being desirable for an attendant to work the lift, he thought it was absolutely necessary for the safety of the public that a skilled attendant should always be provided.

It was stated, p. 132, that the accumulator gave a useful effect of 75 per cent.; but it had been shown by the experiments of Sir Wm. Armstrong & Co. that the useful effect was really as high as 90 or 93 per cent. The friction of the ram in hydraulic lifts was mentioned, as if it were rather a serious matter; but in experiments he had made some two years ago, he had found that a 9-in. ram, with 110 ft. head of water upon it, did not require more than 2 lbs. per sq. in. pressure to overcome the friction of the leather collars, chains, wheels, counterbalances, and all the moving parts. Taking into consideration the fact that the cage in this case fitted very closely to the guides, which of course increased the friction, he thought this showed a very small amount of friction for an apparatus capable of lifting 19 to 20 cwt. At page 133 it was stated that gas engines were suitable for driving pumps for hydraulic lifts; but he thought a gas engine was an expensive machine to use for such a purpose, especially when it was possible to have a direct head of water from a tank. With regard to low- and high-pressure lifts, he thought that low pressures were to be preferred, because of their smaller leakage, and the fact that they could be used after the pumping engine had been stopped for some hours; while the wear and tear was very much smaller, and the risk from bursting pipes was also reduced. Where two or three lifts only were worked in one place, low-pressure were certainly much more economical than high-pressure lifts.

As to the hydraulic lifts at the Seacombe pier, p. 134, it appeared to him that the credit of this plan was really due to Mr. Edwin Clark, from whose design almost exactly the same thing had been put up at Anderton on the River Weaver.* The method had also been used in many other instances, especially in the north of England. As to the question why hydraulic lifts were not more generally used for raising passengers and goods, p. 135, the principal reason was that people in too many instances had not the courage to make the necessary outlay; they looked more to their pockets than to the important element of saving human life.

Before sitting down he should like to refer to a statement made by Mr. Walker in reference to worm gearing. He himself quite agreed

* See Proceedings Inst. C.E., vol. xlv., p. 107, for a description of this lift.

with Mr. Ellington that there was an immense loss of power from the friction of worm gearing; and he considered it was the worst form of gear that could possibly be used for lifting. With regard to belt gear, he also agreed with Mr. Ellington, as against Mr. Walker. He had seen serious accidents arising entirely from the breaking of the belt. In those cases there had perhaps been no safety gear, or at any rate only of a very poor description. With regard to pitch chains, although they could be used in many cases very conveniently, he thought they were the most dangerous form of chain that could possibly be used for a passenger lift. As far as he was concerned he would never, if he could help it, allow a passenger to travel in any lift raised by a pitch chain. Coming back finally to the hydraulic lift, whether it was of the high-pressure or low-pressure kind, he thought a continuous direct-acting ram was the only perfectly safe lift in use at the present time, suitable equally for passengers and goods.

Mr. Alfred Davis said that perfect safety, particularly in the case of passengers, was no doubt a most desirable element in lifts; but all mechanical contrivances were more or less unsafe, and, as a matter of fact, when required they were generally out of order. There was however one form of safety apparatus, invented by Mr. Ellithorpe, which was free from that objection, and which was now being very extensively used in America. The lift chamber, Fig. 25, Plate 21, was continued below the surface of the ground as an air-tight well, the depth of which was, as a rule, about one-eighth or one-twelfth the height of the lift; it was slightly contracted towards the bottom, and the cage had a washer of india-rubber or leather round the bottom edge. Then, in case of a fall of the cage from any cause, the resistance of the cushion of air in the well completely broke the fall. He had himself in several cases seen glasses of water and eggs placed in the cage, and, after the rope had been cut or the cage liberated, not a particle of water had been spilt, and the eggs had remained quite intact. He had been told that many passengers had also been allowed to fall, in some cases 80 or 100 feet, and had suffered no injury. It had also been proposed by Mr. Ellithorpe, and carried out in some cases, he believed, to make the shaft of the lift and the

doors perfectly air-tight, and thus make the shaft answer the same purpose as the air-tight well; so that in case of an accident the cage, instead of falling to the bottom, only dropped a few feet. In that case a flap-valve A was provided at the bottom of the shaft, opening inwards, so as to admit air freely when the cage was rising; while there was sufficient leakage round the bottom edge of the cage to allow of its descent at the ordinary rate. He believed the principle of the air-tight well—not that of making the entire shaft air-tight—had by this time been applied to a large number of lifts in America, and up to the present time had given great satisfaction.

Mr. R. H. Tweddell thought the paper was a very interesting one, especially as Mr. Ellington had made a specialty, and successfully so, of distributing hydraulic power to small consumers; and in connection with lifts he had, at all events, made certain suggestions which were deserving of attention. The only fault he could find with the paper was that it advocated one particular system too much at the expense of others. For instance, great doubt had been thrown on the efficacy of chains. Now in many cases, quite as important as that of lifts, lives were entrusted to ropes or chains, as in the case of mines, ships' cables, &c.; and where accidents occurred they could generally be traced to using tackle having too small a margin of strength, with a view of economising in first cost. Cheapness should not enter into the consideration of any machine, such as a lift, where human life was at stake; but if sufficient care was taken in the choice of the chains, a sufficient margin of safety allowed, and the apparatus duly attended to after it was put up (which was one of the most important matters), he thought there was still room for the use of chain lifts in many cases.

With regard to Mr. Ellington's lift, the fact that it required no head-room for drums or cylinders would sometimes be an advantage; and the whole design was undoubtedly an improvement on the French system referred to, especially in the principle of using hydraulic power throughout the whole system.

He could not agree with the remark, p. 122, that it was an advantage in the case of a burst cylinder or pipe that the hemp

packing of a direct-acting ram served as a brake. If so, it was a brake of a very expensive description, because it must be on all the time of working; and he should much prefer some other means of retarding the descent in such an emergency, rather than having to tighten up the packing so much as to perform the function of an automatic brake every time the lift descended. With reference to the use of wire ropes, he had no doubt they were tolerably safe, if there could be sufficiently large drums for them to work over; but he had had some experience with wire ropes in connection with lifting weights of about 30 cwt., and the useful effect obtained was very small. With reference to the speed of working, all the results given in the Table, p. 136, were based upon comparatively slow speeds; but the author remarked, p. 130, that he had succeeded in working his lifts at a speed of 200 feet per minute. That was very different from any of the tabulated results, where the speed of ascent, with the cage loaded, in no case exceeded 50 or 60 feet per minute; and he should like to know whether the higher speed produced any better effect; he should imagine quite the contrary.

The ratio of length to diameter of ram, as given in the Table, page 136, was in one case as much as 223 to 1; and it would be interesting if Mr. Ellington would state what his experience was with respect to such very long and thin columns and the strains upon them. Supposing the cage was to jam by any accident, and there was an excess of pressure, what would happen? With reference to the remark, p. 126, about the difference in the stress on such a column, according to the point where it was taken, there could be little doubt about that. It was an interesting fact, and very apt to escape the notice of those who were not continually engaged in such work. No doubt however the ram should be made as small in diameter as was consistent with safety, because where there were lifts, as in numerous cases at the present time, going up 500 or 600 or even 800 times a day, any question of economy in consumption of water became of great importance; this of course did not apply to Mr. Ellington's lift, and some others also.

The paper, in describing the other forms of lifts, omitted any allusion to the Cyclic Elevator, of which there were some at work in

the City, and which worked continuously, passing round a drum at top and bottom. Perhaps Mr. Ellington could give some explanation of how that was arranged. Speaking of curious lifts, he might refer to the opera-glass lift, patented by Bramah in 1812, and described by him in terms not so modest as those used by the author of the paper in reference to his invention. Mr. Bramah, after describing how he proposed to lift and lower weights by a compound lift, on the principle of the opera-glass or common sliding telescope, explained it thus:—"For instance, suppose I cause five hundred tubes of five feet in length to slide one within another, perfectly air and water tight" (then followed certain details of construction, and he continued) "then it must appear that, when all these tubes are slided out to their ultimate bounds, the aggregate altitude will be $5 \times 500 = 2500$ feet, and which can be performed if required in a few seconds of time." Mr. Bramah evidently had a high opinion of this invention, for he concluded by saying that "this patent does not only differ in its nature, and in its boundless extent of claims to novelty, but also in its claims to merit and superior utility, compared with any other patent ever before sanctioned by the legislative authority of any nation."

Mr. W. E. RICH thought the first thing to be observed in the construction of lifts, where life was at stake, was to make them safe; and that condition was best ensured by making them as simple in their details as possible, with few working parts and large margins of strength. For efficiency's sake they required as few piston-rod and piston packings as possible; but Mr. Ellington had introduced five times as many packings in his new lift as were required in the ordinary direct-acting lift. He had four in his accumulating apparatus, Plate 16, namely, two stuffing-boxes and two pistons, besides the packing of the lift ram. Now he was certain that those packings would in actual practice be a source of great inconvenience. The packing-up and renewal of leathers, if leathers were used, or the introduction of new packings, if hemp packings were used, would be a source of much more frequent work for those who had to keep the lifts in order, and at the same time the efficiency of the lift would be immensely reduced. If with an

ordinary balanced-ram lift 60 per cent. of efficiency could be obtained, he thought not more than 50 per cent. would be obtained with the form shown in Plate 16. M. Heurtebisé had gone in the same direction, Plate 15, but only half as far, his lift having two extra packings instead of four. He himself failed to see in what the greater safety of that type of lift consisted. In case of the bursting of a cylinder in such a lift when near the top of its stroke, serious results could scarcely be avoided, as the ram would descend with nearly the full velocity due to the height, while under similar circumstances the ordinary ram lift, with counterweights, would descend at a reduced velocity, just as occurred in the well-known Attwood machine.

He thoroughly endorsed the remark, p. 119, that "workmen and others are in the habit of travelling in goods lifts, and a prohibition against this practice is productive of inconvenience. Considerations of expense however will often stand in the way of the adoption of the safest kind of lift for goods alone." He thought that employers at the present day needed to be very wary if they trusted their servants in goods lifts which they would not consider safe enough for passengers. He had not met with any such case since the Employers' Liability Act came into force; but he should think that, in case of accident, it would go badly with employers who had considered a lift safe enough for their servants to travel in, but at the same time not safe enough for passenger use. That was yet another reason for hesitating to employ any lift with elaborate gearing, where human life was at stake.

Again, he thoroughly endorsed what was said, p. 120, as to safety apparatus. The note at the bottom of that page was, he thought, especially suggestive, namely that out of eleven elevators, whose fall was reported, only two were unprovided with safety catches. He did not himself remember any case in which a lift accident had been prevented by a safety catch. What were called safety appliances for hydraulic and other lifts were innumerable, and nearly all, when in perfect order, would probably be effective if the chain or rope were suddenly chopped through close above the cage; but that was a condition of things that rarely existed. An accident might of

course take place in that way; but in a geared lift, at any rate, something generally broke at some distant part of the mechanism, and left a residual strain on the rope or chain, which was quite sufficient in an ordinary way to prevent the catches from coming into play. In most cases of accidents to geared lifts, it was also found that on the day in question the safety apparatus was out of order. The fact was it was nobody's business to attend to it, and probably it had been out of order for years. Similarly the brake apparatus referred to in connection with hand-power lifts, p. 121, were not reliable; indeed he believed some accidents were actually caused rather than prevented by the suddenness with which some brakes and safety gears came into action.

With regard to the column of efficiencies given in the Table, p. 136, for various types of lifts, the author had, in his opinion, overstated them, owing to the method of calculation employed. On checking the efficiencies from the data furnished by the earlier columns of the Table, it would be found that the results given were a mean between the true efficiency of the machine (as determined from the equation given by the author in the note appended to the Table, p. 137) and 100 per cent., as was in fact explained in the same note. It could not be too clearly defined and maintained, in discussing questions before this Institution and elsewhere, that the mechanical efficiency of any rotative or reciprocating machine was the ratio of the net useful work done to the gross work done throughout one complete cycle of its operations. A lift could not be considered to be in a condition for working efficiently until it was able to descend easily when empty; and its efficiency at any speed should be determined directly from the useful or live load which could be raised by it in that condition at that speed, exactly as the author had shown in his equation. Thus the efficiencies of the several lifts in the Table, p. 136, should stand as follows for the stated speeds of ascent and descent:—

No. of Experiment.	Ascending Speed of Loaded cage.	Descending Speed of Empty cage.	Efficiency of Machine.
No.	Ft. per min.	Ft. per min.	Per cent.
1	40	112	52·6
2	28	66	55·0
3	35	47	60·0
4	29	62	57·1
5	55	98	59·8.
6	30	57	52·2
7	19	71	56·6
8	57	62	53·6
9	47	156	61·2
10	60	48	70·0
11	60	81	54·6
12	53	82	57·1

The efficiency of a hydraulic lift reached its maximum when working at the lowest possible speed. In order to work at a speed fast enough to be practically serviceable, some efficiency must be sacrificed, the loss being expended in overcoming fluid friction in the pipes and valves; the faster any lift was worked the lower its efficiency became. Thus it resulted that the speed of a lift was practically limited by the size of the pipes.

Mr. Jeremiah Head said allusion had been made by Mr. Colyer to direct-acting steam lifts. These were largely used for mineral and goods purposes in the North of England, especially at foundries, where the use of a long inverted cylinder as a lift for the cupolas was very common indeed, and worked remarkably well. Steam cylinders would probably do anything that hydraulic cylinders would, in the way of lifting, provided they were made proportionate; but the objection, as he took it, to using steam cylinders for such purposes lay in the elastic nature of steam as compared with the inelastic nature of water. For instance, if the lift stuck by reason of extra resistance at a particular point, then the steam rose in pressure under the lift, and when the resistance was overcome the cage ran away, or, as the workmen called it, "snatched." At one set of blast furnaces in the Cleveland district there was a

direct steam lift—a ram coming up out of a well, which raised the materials for the furnaces perhaps 60 or 70 ft. There had been a very bad accident with that lift some years since, not owing to any snatching in going up, but rather in coming down. The lift had got to the top, and the handles had been so placed as to allow it to go down, but for some reason or other it stuck. Of course the steam all escaped from beneath the ram; and then the latter got free, and came down with a run, causing terrible damage. Such a thing could not happen with water, as long as it had to be forced back against a head.

With regard to economy in lifting heavy weights to great heights, they could not do better than turn their attention to the method adopted in collieries. There all sorts of ways had been tried in past times, and they had come round to one particular method, which was now prevalent everywhere, namely an engine winding and unwinding a rope upon a drum, this rope passing over sheaves and down the pit. There was possibly one improvement on this, which might be mentioned, and that was a lift designed by Mr. R. Howson for Messrs. Samuelson's furnaces at Middlesbrough. Here there was a second staging, 10 or 12 ft. above the charging staging at the top level of the blast furnaces, and on this a regular engine-house was built. That engine-house contained a double drum, having a cog-wheel around the periphery; into that wheel geared a pinion, which was worked by an inverted engine direct. By that arrangement the sheaves to alter the direction of the rope were saved, and it was as direct a lift as could possibly be conceived. It was in fact a return to the old-fashioned arrangement for drawing water from a well by means of a horizontal rope-barrel, with ascending and descending buckets balancing each other. The only thing to be taken up to the full height of the engine-house was the steam, which of course lifted itself. The engine-house at the bottom, where room was very valuable, was got rid of; and being a direct lift, constructed with only one pinion and wheel, it seemed to him about as safe an arrangement as could possibly be conceived. Attached to the cages were double steel-wire ropes, each one sufficient to carry the whole weight if the other should break.

Mr. Ellington, in reply, said he had to congratulate himself on the general consensus of opinion, that there was only one really safe style of lift to be adopted for passenger use in buildings, namely the direct-acting ram. That was going a long way towards the special solution of the problem which he had endeavoured to lay before the Institution.

Mr. Walker had expressed his belief in the direct-acting principle, but then proceeded to say that he also had confidence in a safety apparatus, because he had known cases in which it had been successfully brought into operation. He himself did not doubt that for a moment; but the question was whether such apparatus could be always depended on, and he thought no one would really maintain that they could be. Mr. Rich had pointed out the true cause of many failures in safety apparatus, which was that it could not come into operation except when the chain broke in a particular way. That of course was the way always selected when the apparatus was shown off. As an illustration of how accidents happened, he might mention that he had known several instances in which the cage of a lift such as that shown in Fig. 7, Plate 12, had stuck; and if there was no counterweight to the ram, and the valve was open to the exhaust, the weight of the ram itself was sufficient to exhaust the water, the ram descended, and the ram chain gathered into a heap on the ground below the winding drum. If by any means the cage happened to be released by somebody jumping into it, or by overcoming the resistance in some way, the safety apparatus could not act, because the lift chain had to be unwound off the drum by the descending cage; consequently the cage fell, until it was suddenly brought up when the chain became taut. The apparatus which Mr. Davis had mentioned was applicable in all cases; but even that, it was evident, might sometimes fail.

In reference to the gas engine, Mr. Walker advocated its use for pumping with hydraulic machinery, as recommended in the paper. It being best and safest to use hydraulic machinery in lifts, it did not matter whether the power was obtained by steam or gas engines, or whether it was ready stored in street mains or in a tank, so long as the most economical means available at any particular place for obtaining the pressure were adopted.

With regard to Mr. Colyer's remark on the lifts at Seacombe, he would point out that they were not constructed at all upon the system adopted by Mr. Clark for the Anderton canal lift. The only connection between the two designs was that in both the two lifts were connected by a valve, so that as one went down loaded the other went up empty.

Mr. Colyer had further stated that it was not the fact that there was a limit to the height of lift with a direct-acting ram. This statement was only correct on the supposition of there being a balance weight and chains on the lift; there was then no limit to height. Supposing however there was nothing but a direct-acting ram (which was the point he wanted to arrive at), and excluding the effect of the hydraulic balance, there was a limit, with a given pressure, to the height to which the lift could be raised, as was clearly shown in the paper. Mr. Colyer also stated that almost any speed could be obtained with any high-pressure hydraulic lift; but his own experience was that, in the particular case of a chain-balanced lift, such as shown in Fig. 11, Plate 14, it was impracticable to obtain high speeds of working, excepting of course with exceedingly high pressures. He did not know of any instance of a lift of that kind, with pressures of water under, say, 200 lbs. per sq. in., which worked at speeds of anything like 150 ft. per min. with a load. If there were any such instances, he should be very glad if gentlemen knowing of them would furnish data about them similar to those given in the Table, p. 136.

In reference to Mr. Tweddell's remarks, he himself was also of opinion that in a great many instances a chain lift was the right thing to use; but only in cases where a direct-acting ram lift was impracticable. He also agreed that, if a chain lift was properly constructed, if all the parts of the chains and attachments were exactly as they should be, and if the superintendence was good, there was reasonable security in the use of such a lift. His point was that that superintendence as a general rule was not good, and that in the majority of cases such lifts were not made in accordance with the best rules; and therefore, speaking as to general practice, he did not think that the system was one to be recommended.

With regard to the particulars of efficiency given in the Table, p. 136, there was a very good reason for taking the observations at the slowest practicable speed at which the lifts could be worked. If any increased speed had been taken, of course a lower efficiency would have resulted; but the unknown effect of the friction of water in the pipes, valves, and passages, would have made the results of no value for purposes of comparison. The observations were all taken from lifts which had been actually working, some for many years, and some only a few months. He had however given in the Table the maximum speed attained, when the lift might be said to have been doing no useful work, and the whole of the power was absorbed in friction, excepting that amount which was needed for lifting the dead load subsequently used to bring the cage down. The net loads lifted as given in the Table did not include the weight required to bring the cage down empty at the working speed of descent; and the column of efficiencies gave the ultimate efficiency when the cage was just balanced. In many cases of passenger lifts this latter would be the most desirable working condition; but the precise margin of power allowed must of course depend on the special circumstances under which each lift was to work.

He quite agreed with Mr. Rich in the statement that, as a general rule, the practical efficiency obtained with hydraulic lifts was a great deal less than the ultimate efficiency of the machinery as given in the Table attached to the paper; but he must entirely dissent from Mr. Rich's view of the real efficiency, as explained in the figures given by him. The comparative friction of the various types of lifts was the point he was himself desirous of recording. The Table given in the paper did not contain any appreciable error, the only assumption being that the total loss by friction in ascent and descent was constant during the whole motion: this assumption was necessary, owing to the condition under which the tests were made rendering it impracticable to ascertain directly the gross weight raised. In Mr. Rich's figures the efficiency was made to depend upon the particular working arrangements adopted, which would give very variable results in practice. In illustration he would take a lift like

that shown in Fig. 9, Plate 13. The particulars of experiments with that lift were as follows:—

Pressure of Water, lbs. per sq. in.	620 lbs.
Diameter of Ram	$3\frac{1}{2}$ in.
Stroke of Ram	40 ft. 6 in.
Height of Lift	40 ft. 6 in.
Ratio of Height of lift to Stroke of ram	1
Net Load lifted	$21\frac{1}{2}$ cwt.
Gross Load lifted	$48\frac{3}{4}$ cwt.
Ascending Speed of Loaded cage, ft. per min.	40 ft.
Ascending and Descending Speed of Empty cage, ft. per min.	160 ft.
Apparent practical Efficiency	40·4 p. c.
Maximum Efficiency in ascending with gross load	91·7 p. c.

In this case the weight of the ram and cage lifted was known; and the efficiency, on the basis he had adopted and which he maintained was correct for the purpose intended, would be 91·7 per cent.; whereas the efficiency on Mr. Rich's method would be 40·4 per cent. But this latter was not at all the real practical efficiency; for it happened that, as a matter of fact, the load raised by this lift never exceeded 10 cwt.; and the practical efficiency obtained would therefore be reduced to 18·8 per cent. Further, without any alteration in the above lift, but simply by the addition of the hydraulic balance, attached either to the supply or to the exhaust pipe, and constituting a second machine having a separate efficiency of its own, the efficiency of the lift would, on Mr. Rich's basis, be *increased* from 40·4 to say the 70 per cent. given in No. 10 experiment, p. 165 (notwithstanding his statement that the addition of the hydraulic balance lowered the efficiency); while on his own method the ultimate combined efficiency would appear to be, as it really was, *reduced* from 91·7 to say the 85 per cent. given in No. 10 experiment in the Table, p. 136.

It might also be pointed out that, as a general rule, loads had to be lowered as well as raised; and as stated in the paper, page 130, the particular arrangement of hydraulic balance, as shown in Fig. 17, Plate 16, permitted this fact to be turned to useful account for increasing the lifting power in the ascent of the loaded cage. When

working the lift in this way, the efficiency on Mr. Rich's assumption would be apparently as much as 100 per cent. The true loss by friction at constant speed being practically constant, a method of calculation which would produce these anomalous results could not be accepted as being of any scientific or practical value. There could not of course be any real difference between Mr. Rich and himself on this matter. The Table of efficiencies in the paper had evidently no reference to the practical efficiency realised under ordinary conditions of working; but it gave the maximum efficiency under the most favourable conditions when the cage was just balanced. Mr. Rich had given a column of what might be termed the practically useful effects under one particular condition of working; but the efficiency thus obtained was limited to that particular condition, and was not the maximum. It was worth notice that Mr. Rich's column of efficiencies gave a much greater proportional increase of efficiency for the author's hydraulic-balance lifts than was given by the Table in the paper.

As to the length of the ram subject to compressive strain, the greatest proportion of length to diameter that he had himself used was something under 180 to 1. In the case of the greater proportion referred to by Mr. Tweddell (No. 9 in the Table, p. 136) the ram was for half its length in tension. He was aware that there was a want of experimental data as to the behaviour of long columns under strains such as those upon the ram in a direct-acting hydraulic lift. He believed the proportion of about 120 to 1 was the greatest at which any reliable experiments had been made; but the above proportion of about 180 to 1 he had used in lifts for many years, and they had given exceedingly good results. In the case of No. 3 in the Table, there was a 3½-inch ram with a stroke of 50 ft. 6 in., being the lift constructed as shown in Fig. 16, Plate 16. That ram had been loaded, without any guides at all to support it, with about twice the working load, and under those conditions the bending of the ram was of no moment. He had also run that lift up at full speed, without any load on, against the stops at the top. There was a slight spring, and it then came to a stand without any damage to the ram or to the machinery. As a rule, the rams for these hydraulic-balance lifts

were made of solid steel. Of course it was possible to get solid bars very much longer than hollow tubes, so that joints could be avoided, at any rate in the centre; and steel might now be got so tough that such a ram might be tied in a knot without fracture. Moreover, directly the deflection of the ram, from any cause, became at all serious, the friction on the guides would be so great that the lift would necessarily stop.

Mr. Tweddell had asked for particulars of the revolving or Cyclic lift. He had ventured in such a lift, but certainly for general use in dwellings it was not the right thing. He thought it a decidedly dangerous arrangement. There were no doors either to the lift or to the well. It was extremely slow in its action, and it was made with the plate chains which Mr. Walker advocated, but which Mr. Colyer condemned. No doubt a plate chain in some circumstances was a very good thing, but on the whole he would rather have a short-link chain for continuous use.

Mr. Rich had expressed his preference for a chain-balanced direct lift. No doubt if that gentleman had to do with the construction of such a lift as was shown in Fig. 11, Plate 14, it would be made to all intents and purposes secure; and he himself should have no hesitation in going up in it at any time. But the security would be due to the good construction of the lift, the principle being defective. An accident such as that at the Grand Hotel in Paris was quite possible, not so much from the breakage of the chain, as from the breakage or disconnection of the ram from the cage. Mr. Colyer had suggested that the point noted in the paper, as to the strains upon the ram being in tension at one portion and in compression at another, was of very little moment; that it was a purely theoretical matter. If however that theoretical matter had been borne in mind by the constructor of the Grand Hotel lift, he believed the accident would not have happened. Probably it had been thought that the ram was only pushing the cage up, and that therefore its connection with the cage was a secondary matter; but if it had been considered that the upper part of the ram was practically hanging from the cage, it would rather have opened the designer's eyes to what was the true character of a direct-acting chain-balanced lift, as regarded security. Practically

it was this, that the ram and its cylinder became a safety apparatus to the lift, while the motion was due to the counterbalance.

He could quite understand Mr. Colyer's advocacy of a low-pressure lift, for he also preferred counterbalance weights and chains, which were unsuitable for use with high pressures. Taking for example a lift 90 ft. in height, the working pressure being 700 lbs. per sq. in., obtained from a system of public hydraulic power, it would be necessary to abandon the direct-acting ram unless the hydraulic balance were introduced, for otherwise the cost of the power would be prohibitive. The smallest area that could possibly be given to the ram would still be sufficient, when subjected to so high a working pressure, to lift not only the load, but the weight of the ram and cage as well; and it would be useless to balance the lift at all with a chain and weight. But the principle of his own hydraulic balance was that the lift could be constructed with a ram of any required size to give security, and by the addition of a second ram of any convenient stroke, alongside that lift-ram, the latter would be perfectly balanced, its displacement would also be balanced, and the same balancing effect would be obtained as that due to a heavy chain and counterweight in a low-pressure lift; thus realising the advantage of high pressure, without sacrifice of economy and with additional security. The addition of this second ram certainly compared favourably in point of complication with chain counterweights and head gear. Moreover with a high pressure of water the lift could be worked without a balance at all, since the balance in such a case as that shown in Fig. 18, Plate 17, was really only an economiser of power. Therefore in case of any serious derangement, or need of packing a gland or inserting a new leather, which Mr. Rich feared would often happen, then, if working at high pressure, the valve shown in Fig. 20, Plate 17, might simply be closed, and the lift might continue to be worked without the balance until all was made right again. But in using hydraulic rams it was not absolutely necessary even to use a balance constructed as shown in Figs. 17 and 19. Taking Fig. 15, Plate 15, as an illustration, the lower cylinder B would be made of smaller capacity than the upper cylinder D. There would

thus be a differential arrangement, and the cylinder A could be reduced, and the whole of the counterweights and chains E could be taken away; precisely the same effect would then be produced as with the balance arrangement shown in Fig. 17, Plate 16. There was yet a further simplification, in which the lower cylinder B, Fig. 15, could be dispensed with altogether. But those were matters of detail. The practical results of the working of the lifts, Figs. 17 and 19, were given in Nos. 3 and 10 of the Table, p. 136; and under similar conditions they did actually give a higher efficiency than the direct-acting chain-balanced lifts, Fig. 11, even when the former were working with a lower pressure of water.

There was also a very curious effect produced by his hydraulic balance arrangement, as compared with a low-pressure chain-balanced lift; and that was that a higher speed of lift was obtained with the former, using the same quantity of water in both cases. He believed the effect to be due to the diminished wetted surface of the lift ram, and the low velocity of the balance ram, in his hydraulic balance lift. This fact also confirmed his statement of the higher efficiency of the hydraulic balance system. The arrangement of the balance cylinder gave a multiplying power, as regarded the length of stroke in the lift cylinder, in the proportion of about 8 to 1. Therefore the whole formed a sort of hydraulic gear, increasing the stroke and pressure in the lift cylinder. He had tried the lift, Fig. 18, Plate 17, without the balance and with it, and it lifted exactly the same load. That showed that the weight of the ram, shown in section, Fig. 19, which was a hollow ram only about $8\frac{1}{2}$ ft. long and 11 in. in diameter, was sufficient to overcome the whole of the friction on the glands of the balance cylinder, both during descent and ascent. The saving effected by the use of the balance apparatus in many cases was as much as three-fourths of the total power that would have to be used if there were no balance, or if a chain balance were adopted. In that particular instance, Fig. 18, the saving was about one half. The saving depended on the working pressure, and the proportion of the load to the weight of the ram and cage.

The subject of colliery lifts, referred to by Mr. Head, was worthy of discussion by itself. They were so very distinct from

anything he had dealt with in the paper, that he could hardly go into the question after the length of time he had already occupied.

The President said the members would agree with him that they were much indebted to Mr. Ellington, and also to the gentlemen who had taken part in the discussion, for giving them the benefit of their experience on this subject. It appeared to him that the keynote of the paper was the question of safety to life and limb. All who, like himself, had had anything to do with machinery of that kind would feel the importance of that question, and would be very careful to proportion the parts properly, and to make them sufficiently strong to be thoroughly safe. A great many of the accidents that had occurred were traceable to a deficiency in the strength of the parts; certainly that unfortunate accident in Paris might be traced to that cause. The question of the comparative safety of the chain lift and the direct-acting hydraulic lift was thus a very important one. The chain lift was dependent upon the security of all the welds in the chain, and there must therefore be some means of catching the cage in case of the chain breaking. The experience he had had during the last thirty years enabled him to say that he had not lost faith in appliances of that kind. Arrangements were now being carried out whereby there was a chain for lifting the load, and a wire rope running alongside the chain, over a separate line of pulleys, and attached to the safety apparatus, which gave additional safety to the arrangement. Then came the question, could the apparatus be kept in good order? because he quite agreed with the remark that such appliances were often allowed to get into bad order, and when the day came that they should be in working condition they were not so. The arrangement he had spoken of corrected that evil in a great measure, and the attendant would also be bound to keep the chain and the rope adjusted. He quite agreed that the direct-acting lift in its simplicity was probably the best machine that could be used for lifting, but it could not be applied under all conditions, nor, so far as he knew, had a reliable safety apparatus been applied to hoists of that construction. It was perhaps not altogether so safe as was supposed. The lift

cylinder was suspended in a hole or well, where it was never seen again; and if one of the joints were to blow out, or if the bolts were to rust and give way, or the valves or pipes were to burst, the escape of water would be sufficient to let the cage down at a rate that would certainly cause damage to life and limb.

The arrangement of an engine at the top of the shaft, described by Mr. Head, was one of the best that could be made; but it was extremely difficult and objectionable to carry this out in buildings. He thought it would be better if, in the case of large buildings, the architect would sometimes consult with the engineer before completing his arrangements. Some architects appeared to consider that machinery might be stuck in any dark hole. He himself thought that machinery upon which life and limb depended should at all times be visible; instead of being in a dark hole, it ought to be in a bright chamber; then there would be some chance of its being kept in proper order.

Mr. Ellington asked permission to make one or two further remarks in reference to the President's observations, and also to the remark made by Mr. Rich, that a lift of the hydraulic-balance construction would be more liable to accident, in case of a burst cylinder—which was of course a very remote contingency—than a lift of the direct-acting chain-balanced kind. The essence of his own hydraulic balance was that the lift-cylinder A, Plates 16 and 17, was a high-pressure cylinder; that being the case, there was but a small quantity of water in it, and the cylinder itself was small. All who had had to do with high-pressure hydraulic lifting machinery would know that practically it was much easier to deal with high than with low pressures, as regarded safety; because for high pressures the parts could be made much stronger in proportion, without unduly increasing their size and weight. Further, there was this very important advantage in a hydraulic-balance lift, such as those shown in Plates 16 and 17, namely that there was a much smaller mass in motion than in a chain-balanced lift, Fig. 11. In the latter there was the larger ram, the heavier cage, the massive chains, and the counter-weights; and if anything suddenly checked the water in the cylinder there was a considerable shock. If the lift were travelling at a high

speed (and this was one of the practical difficulties in working high-speed lifts on that system), then, since the counter-weights were travelling at the same speed and in the same direction as the ram, relatively to the water in the cylinder, there would be, in case of a check, a serious shock due to the combined effect; for the counter-weights, if stopped too suddenly, would cause the lift to over-run, and so leave a space between the water and the ram; and after the speed was checked, the ram would come down again upon the water with a blow, the effect of which would be much greater in a large cylinder than in a small one. On the contrary, with the hydraulic balance in Plates 16 and 17, there was a lighter mass in motion, and the balance ram was working in a contrary direction to the lift ram; so that the whole machine was just like a lever loaded at both ends and resting on a pivot, and the same shock was not liable to occur in the lift cylinder, the ram always resting on the water.

With reference to the remarks of the President as to the application of a safety apparatus to a lift of the direct-acting construction, he might mention that he had designed, and made some successful experiments with, an automatic hydraulic brake, which could be applied to his hydraulic balance lifts, though not to the ordinary chain-balanced direct lifts. In a chain-balanced ram lift the pressure in the cylinder was hardly anything when lowering, and it was the full working pressure when lifting. In the hydraulic balance lifts there was always a considerable pressure in the lift cylinder, say 300 lbs. per sq. in. when lowering, and 400 to 500 lbs. when lifting. The action of the automatic hydraulic brake was dependent on this fact; and its construction was shown in Figs. 26 and 27, Plate 21. The lift ram R was embraced by two brake-blocks AA, which by a system of toggle levers were connected with the piston-rod B of a piston C, working in a small hydraulic cylinder. The back end of the piston at D communicated with the pressure water, and the front at E with the lift cylinder. If the lift cylinder burst, and the water escaped from it with a velocity sufficient to reduce the pressure within it so far that the lift descended quicker than its normal speed, the excess of pressure on the back of the piston D, not connected with the lift cylinder, caused the piston

to move forwards in the brake cylinder, and so made the brake clip the ram. By connecting the two inlet pipes of the brake cylinder through a suitable valve, the brake could be controlled by hand from the lift cage, and could be conveniently used for locking the lift in any desired position, which was the object he had in view in designing the arrangement. It must of course be understood that the apparatus was liable to all the unforeseen contingencies of other brakes or safety appliances; and as, after all, dependence must be placed on something, he preferred to depend upon a well-made hydraulic cylinder and ram. The breakage of a hydraulic cylinder was a very remote contingency, and even in case of breakage serious consequences could hardly occur; but if an automatic brake were needed to perfect the system, it could be applied in the way now described.

ON APPLIANCES FOR WORKING UNDER WATER, OR IN IRRESPIRABLE GASES.

By Mr. W. A. GORMAN, of London.

History of Diving.—In bringing before the Members of this Institution the following paper, the author does not intend describing at any length the early history of diving.* From the earliest times divers have been employed in fishing for pearls, corals, and sponges, and have been accustomed, before descending, to place a piece of sponge soaked in oil between their teeth. This is said to have enabled some of the most hardy to remain at least six minutes under water.

The records of the earlier attempts to provide some artificial supply of air to divers under water are unsatisfactory. Roger Bacon (A.D. 1240) was supposed to have originated a machine for working under water. The invention of the diving bell is generally assigned to the sixteenth century. The first account of its use in Europe is that of Tasnier, who relates that in 1538, at Toledo in Spain, he saw two Greeks, in the presence of Charles V., let themselves down under water in a large inverted kettle without being wet.

Lord Bacon, in his "Novum Organum" (A.D. 1600), describes the primitive method adopted in his time, in which there was no

* Those who take an interest in the subject are referred to Lord Bacon's "Novum Organum;" "Philosophical Transactions," from the time of Halley, 1678; "The History of Inventions," by Beckman; Boyle's "Experimental Philosophy;" the article on Diving in "The Encyclopædia Britannica;" and Messrs. Siebe and Gorman's book on "Diving."

mode of replenishing the air in the inverted vessel, or bell, whilst under water. In 1632 Richard Norwood took out a patent for a special means to dive into the sea.

Borelli, in 1669, constructed a copper vessel two feet in diameter, with glass fixed before the face of the diver; this he termed a "Vesica." It was worn as a helmet, and securely attached to a dress of goatskin. Within the "Vesica" were pipes, by means of which a circulation of air was contrived. An air-pump was affixed to his side, by which the diver was said to condense or rarefy the air within the "Vesica," so as to make himself heavier or lighter, on the same principle as the air-bladder of fishes. Artificial webbing was also supplied to the feet, to enable him to tread the water.

In the latter part of the seventeenth century the diving bell came largely into use. About 1680 a mania arose for undertaking submarine exploration, and companies were formed for that purpose; but through imperfect appliances they were unable to reap profitable results.

About the year 1700 Dr. Edmund Halley devoted much time to subaqueous experiments, and in 1716 he read a paper before the Royal Society, entitled "The Art of Living under Water." In this paper he says, "When there has been occasion to continue long at the bottom of the sea, some have contrived double flexible pipes to circulate air down into a cavity, enclosing the diver with armour, to bear off the pressure of water, and give leave to his breast to dilate upon inspiration, the fresh air being forced down one of the pipes, with bellows, or otherwise, and returning by the other of them, not unlike an artery and vein. This has been found sufficient for small depths, 12 or 15 feet; but when the depth surpasses three fathoms, experience teaches us that this method becomes impracticable, for though the pipes and rest of the apparatus may be contrived to perform their office duly, yet the water, its weight being now become considerable, does so closely clasp the limbs that are bare, or covered with flexible covering, that it obstructs the circulation."

To remedy these inconveniences he turned his attention to the diving bell. His contrivance consisted of a truncated cone of wood, 3 ft. diameter at the top, and 5 ft. at the bottom, and containing 60

cubic ft. In the top was placed a strong glass to give light, and a cock to let out the vitiated air; the bell was coated with lead and weighted, that it might sink steadily; when below it was supplied with air by two barrels of 36 gallons each, which were alternately lowered and raised. He states that he remained one hour and thirty minutes under water, at a depth of 10 fathoms.

In 1721 he described to the Royal Society a method by which the diver could leave the bell. He used pipes, 40 ft. in length, made with spiral brass wire inside; one end being fixed in the bell, and the other to a cock which opened into the diver's cap. This was made of lead, weighing 56 lbs.; and he also wore a girdle of the same weight, and clogs of lead weighing 12 lbs. each.

About the same date, 1716, when Dr. Halley read his first paper to the Royal Society, John Lethbridge invented an air reservoir, made of wainscot, perfectly round and 6 ft. long, 2 ft. 6 in. in diameter at the head, and 1 ft. 6 in. at the foot. He compressed air into this with a pair of bellows, and then lowered it with himself under water, where he remained 34 minutes. Numerous inventors followed in his track.

Smeaton, in 1779, first employed the diving bell for civil engineering operations, in repairing the bridge at Hexham, Northumberland. The apparatus was an oblong wooden box, 4 ft. high, 2 ft. wide, and 3 ft. 6 in. long. It was supplied with air by a pump fixed on the surface.

Soon after the construction of the New Dock at Ramsgate, in 1784, Smeaton employed an improved diving bell weighing half-a-ton: two men worked in it, and were provided with a constant supply of fresh air through flexible pipes, by means of a force pump placed in a lighter which floated over them. Smeaton appears to be the first person who used the air-pump to force a supply of fresh air to the divers, in the bell under water.

A diving dress was invented in 1798 by Kleingert, of Breslau, which consisted of strong tin-plate armour, Fig. 1, Plate 22, in the form of a cylinder encasing the diver's head and body, with a leather jacket and strong leather drawers. These were made waterproof, and joined by brass hoops around the metal armour, so that the diver was relieved

from the pressure of the water except on the legs and arms. He inhaled the air from the surface through one pipe, and the vitiated air was carried up to the surface by another. A diver could not with this apparatus descend to greater depths than 20 ft.

About the same date Messrs. John and William Braithwaite constructed a diving apparatus, with which they carried out several successful operations. In 1805 they recovered £75,000 in dollars from the East Indiaman *Earl of Abergavenny*.

Rennie, whilst occupied on the works of Ramsgate Harbour, in 1813, made considerable improvements in the diving bell; he designed and constructed a diving bell of cast-iron (Fig. 2, Plate 22), 6 ft. high, 4 ft. 6 in. wide, and 6 ft. long, with one side a little heavier than the other, so that it should hang a little out of level, and thus more readily allow the vitiated air to escape. In the top of the bell six thick bull's-eyes of glass MM were fixed to admit light. In the centre of the top was a circular hole, in which a brass lining was firmly fixed. To the under side of this was attached the inlet air-valve E, on a brass grating of the form shown in Fig. 3. The valve itself was simply a disc of strong leather. A nozzle N was fixed to the top of the bell above the valve, and to this was screwed a water-tight leather hose $2\frac{1}{2}$ in. diameter, connected to the air-pump, which was constantly worked by a sufficient number of men. Inside the top of the bell were strong lugs, to which were attached chains FF, Fig. 2, for suspending stones or other material. The bell was fitted with seats BB, and a rail C for hanging the various tools used by the men. It was slung by stout chains A from a double-purchase crab fixed on a truck, which could travel along the gantry; the total weight was five tons. Rennie used this diving bell with great success in the numerous harbour and other works with which he was associated.

The Open Diving Dress.—In the year 1828 or 1829 the late Mr. Augustus Siebe, A.I.C.E., the founder of the author's firm, was applied to by Messrs. Deane to assist them in the construction of a diving dress, afterwards known as the Open-Helmet Diving Dress. The helmet, Fig. 4, Plate 22, was made of copper, with a screw lens in front, and a metal elbow riveted on the back of the head-piece, to connect

the air-pipe with the pumps, the head-piece and breast-plate being in one. To the breast-plate was attached a canvas jacket, which, with the aid of two lead weights, kept the helmet fixed upon the shoulders. Boots with lead soles, weighing 12 lbs. each, were worn, and also a waterproof dress fastened round the neck, over which were placed the helmet and jacket. The air escaped into the water from underneath the outer canvas jacket, and the water reached within a few inches of the diver's mouth, so that he had to work in a vertical position. The air-pumps had three cylinders, 3 in. diameter, 9 in. stroke. Even at the present day many of the coast divers use this form of dress.

The Close Diving Dress.—About 1839, when engaged at the wreck of the *Royal George*, Mr. Siebe, observing the danger attending the use of the open helmet, introduced his invention of the close helmet, Fig. 5, Plate 23, fitted with inlet and outlet valves, I and O, and with a segmental neck screw, to remove the head-piece by one-eighth of a turn. The waterproof dress was fastened to the metal collar by screws and brass bands. Colonel Pasley, R.E., (afterwards Major-General Sir C. Pasley) at once ordered the Royal Engineer divers to be equipped with this dress and helmet; and the operations at the wreck, owing to this great improvement, were carried on with much greater rapidity, and without accident.

The above brief description of diving apparatus in its primitive form will be sufficient to show the progress made up to a recent date.

Modern Apparatus.—This apparatus, as illustrated in Plates 24 and 25, is a very perfect one, combining a high degree of safety with comfort for the diver. The air-pump, Plate 24, is capable of compressing air to a pressure of 240 lbs. per sq. in., and consists of two vertical double-action gun-metal cylinders CC, securely fixed to a bed-plate of gun-metal, which is bolted on the base of two side standards AA, the whole forming a framing to carry the crank-shaft B. Each piston, Fig. 7, is constructed of two inverted cups of leather LL, having leather packing placed between, and the whole is secured by two cast-iron piston-plates MM fitted to the piston-rod inside the leather cups, and pressed together by a nut. Grooves are formed in the

periphery of the piston-plates, to contain expanding springs, which, pressing outwards against the inner side of the leather cups, keep them in close contact with the cylinder, and thus maintain the piston in a perfectly air-tight condition. Each cylinder cover has an oil tap for lubrication.

The piston-rods pass through glands H, packed with turned leather washers, and are extended so as to work in guides KK, Fig. 6. Double connecting slings SS, with gun-metal bearings, connect the piston-rods to the crank-pins. Inlet and outlet valves, I and O, Fig. 7, are fixed in the cover of each cylinder, and also in the base-plate. Spindle valves are used, faced with leather, and having gun-metal seatings, to which the valve is kept by a spiral spring. The top and bottom outlet valves are connected by a passage cast on the cylinder, and leading to the air-delivery nozzle N. The cylinders are surrounded by a copper cooling cistern W, Fig. 6.

Pressure gauges GG show the depth and pressure at which the diver is working, and are also used for testing the air pipes. Each gauge is marked off to represent the pressure in pounds per sq. in. at given depths of water, as given by the following Table:—

Depth Ft.	Pressure lbs. per sq. in.	Depth Ft.	Pressure lbs. per sq. in.
20	8·68	120	52·08
30	13·02	130	56·42
40	17·36	140*	60·76
50	21·70	150	65·10
60	26·04	160	69·44
70	30·38	170	73·78
80	34·72	180	78·12
90	39·06	190	82·46
100	43·40	204†	88·54
110	47·74		

* Practical limit of diving.

† The last figure is the greatest depth to which (to the author's knowledge) a diver has ever descended.

The fly-wheel and winch-handles, fitted on the crank-axle, are

made to be easily removed, and the whole pump is securely fitted in a strong teak case, Fig. 8, Plate 23.

The air-distributing arrangement, by which the air can be transmitted to one or two divers as occasion may require, is as follows. The two outlet nozzles, A and A_1, Fig. 9, Plate 23, are connected by a cross branch-pipe B, and a three-way cock C is fixed at the junction of the pipe B with the nozzle A_1. The position of this cock, when supplying air from both cylinders to one diver, is shown in Fig. 9, while Fig. 10 shows the position when two divers are to be supplied, each being in connection with one cylinder. If at any time the pump is supplying one diver, and it is desired to send down the second diver to his assistance, it is only necessary to turn the lever of the cock C round to the position marked "two divers," Fig. 11, and work the pump faster. The great advantage of this pump is that it can supply air to two divers independently at different depths. Two divers can work from it to a depth of 90 ft., or one alone to a much greater depth.

The improved helmet, Figs. 12 and 13, Plate 25, is made of tinned and planished copper, and consists of two parts, the breast-plate and the head-piece. The breast-plate is so constructed that the diver has free use of his arms, and can reach over the head-piece. It has a segmental neck ring R, so that the head-piece can be removed by one-eighth of a turn, and has a brass band S at the bottom, with twelve screw studs, to which are fitted four brass plates, fastened by wing-nuts, thus forming the junction with the waterproof dress. A is an air passage for conducting the air supply over each lens, so as to prevent the diver's breath from condensing upon the glass. B is a nozzle to which the air pipe is connected, and inside which is placed an inlet valve ; in case of accident to the air pipe the air pressure inside would close this valve, and thus prevent the water from entering the helmet. D is the front lens, which can be unscrewed, so that the diver can converse without being undressed ; and E is the side lens. O is the outlet valve for the escape of vitiated air into the water. G is a stud for securing the weights, and H a regulating tap, by means of which the diver can regulate his supply of air without giving a signal.

Fig. 14, Plate 25, shows a section of the outlet valve, which is placed at the right-hand side of the back of the helmet, and within reach of the diver: it is a metal cone valve, over which is screwed a metal cap C, with small holes drilled in it to allow the air to escape into the water. The valve spindle is kept in position by a hard-drawn copper-wire spring. There is a second brass cap J, screwed on the first one, and having a small opening. In this the diver can insert his finger, and press down the valve spindle, so as to confine the air, and thus inflate his dress and rise to the surface. The valve has a small metal chamber I, carried up a short distance, so that the opening into the helmet is four inches above the valve.

The waterproof dress is made of strong tanned twill, with an india-rubber lining between the thicknesses of the material. It has mineralised india-rubber collar and cuffs. The boots have lead soles weighing 14 lbs. each. At the front and back are lead weights 40 lbs. each. An air pipe with spiral wire embedded in it, and fitted with joints to connect up to any desired lengths; a knife, in watertight case, a leather belt and pipe holder, and a double suit of flannels, complete the equipment. For deep water the men wear a body guard, to keep off the pressure.

Experience in Working.—Some special cases of diving with this apparatus may be mentioned. In the recovery of treasure from the *Hamilla Mitchell*, sunk off Shanghai, in a depth of 144 ft., the diver, Robert Ridyard, worked for five consecutive days five to six hours each day, recovering £40,000 in dollars. The apparatus was used constantly day and night at the raising of the *Eurydice;* on an average eight divers were working together in a strong tide and amongst wreckage, but not a single accident occurred.

When the news reached England that H.M.S. *Doterel* was blown up, the Admiralty at once telegraphed to the ships of war on the station to proceed to the scene of the disaster, as each of H.M. ships carries a seaman diver and also an artificer diver.

H.M.S. *Garnet* was the first vessel to arrive at Sandy Point. Lieutenant Stanley Dean Pitt, R.N., volunteered to accompany George Hunt, artificer diver in making a careful survey of the wreck,

which was lying in 12 fathoms of water; the result being positive proof that the boilers had not caused the explosion, as they were found in perfect condition. The author considers that the apparatus he has described was in this particular case of great service to the engineering world, to say nothing of the importance to the country, as the whole of the armament and other valuable property were recovered.

For engineering works the apparatus is in use at the present time to a considerable extent, at Colombo, Port Elizabeth, Madras, and many other harbours. The average number of hours for the divers to work in water, say to 60 ft. depth, is four. Their pay depends upon their capabilities; but in this country the average rate is £4 10*s.* per week for masons, £4 for carpenters, and £3 10*s.* for labourers. In wrecking operations the divers work at a salvage scale according to the depth, and as a rule earn very good wages.

As so many various handicrafts are required for submarine works, the author's firm have erected a diving tank in their factory, where men are trained, and also experiments carried out. The selection of divers requires much care. Steady habits are essential, and from long experience it is found that men of sanguineous temperament are unfit to bear great pressure, while a man slightly built but muscular, although he may seemingly be weak in lungs, often turns out a first-class diver, and improves in health and strength. Among the many purposes for which the diver is required may be mentioned the following:—The repairs and inspection of dock gates, sluices, bridge foundations, &c.; the removal of pumps and other appliances in shafts; the repair of well-pumps when under water; the cleaning of iron ships' bottoms, and repairing of leaks; the examining or repairing of fouled or damaged propellers, &c.; the sinking of cylinders for piers and bridges; the laying of pipes for gas and water in rivers or harbours; torpedo service; and lastly, fishing for sponge, pearl, coral, and amber.

Appliances for Working in Irrespirable Gases. — The Fleuss apparatus represents a great improvement in this direction. It is self-contained and entirely independent of any communication with

the outer atmosphere, thus enabling the wearer to breathe with safety in the most noxious gases, to walk any distance, and to explore the most intricate turnings of a mine with perfect freedom of action. The principle of the apparatus is that the wearer breathes the same air over and over again, the carbonic acid being absorbed from it after each expiration, and at the same time the requisite amount of oxygen restored to it; thus rendering it pure, and fit to be again inhaled into the lungs.

The apparatus, Figs. 15 and 16, Plate 26, consists of a strong copper cylinder D, 6½ in. diameter, and 12 in. long, with domed ends, and capable of containing 4 cub. ft. of oxygen, at 16 atmospheres pressure: this is sufficient for four hours' respiration. Above the cylinder D is attached a square metal box B, 12 in. × 12 in. × 4 in.; this contains the carbonic acid filter, which is a box of vulcanite divided into four compartments by vertical diaphragms, in such a manner that the exhaled breath of the wearer is made to pass twice up and down through the vessel, before it is in a position to be again inhaled. This box is fitted with small cubes of india-rubber sponge, saturated with a thick pasty solution of caustic soda. The exhaled air, being finely divided as it passes through the interstices of the sponge, and coming in contact with a very extended surface of caustic alkali, becomes thoroughly cleansed of all the objectionable products of respiration.

As shown in Figs. 17 and 18, Plate 26, a flat bag G of vulcanised india-rubber, 12 in. × 15 in., is strapped on in front of the wearer; into this the exhaled air passes from the filter, by means of a tube J of india-rubber. The bag is also in communication by the pipe P, Figs. 15 and 16, with the oxygen chamber D, and the supply of oxygen to the bag G is regulated by a jamb screw-valve T, under the control of the wearer. This valve is also shown half size in Fig. 19. The mask A, Figs. 17 and 18, is made to fit air-tight to the face of the wearer, and is held in place by straps buckled at the back of the head. A band of rubber is made to cover the ears, and the eyes are protected by glass, when it is necessary to go into smoke or gases that would hurt them. The mask is provided with a pair of flexible tubes E and I, with valves, the one for exhaling

E being in communication with the filter B, and the one for inhaling I being connected to the air bag G. The slightest effort of inhalation brings the revivified air freely to the lungs of the wearer. The whole apparatus weighs 26 lbs., and can be adjusted in a few seconds.

The author considers this apparatus particularly adapted for use in coal mines, or when men have to deal with noxious gases. Mr. Fleuss has remained in the densest smoke, as also in a glass chamber charged with carbonic acid, for a considerable time. His apparatus was regularly used for some time at the Westminster Aquarium, and also more recently at the re-opening of the Maudlin seam of the Seaham colliery, after the fatal explosion of September 1880. The author has to thank Mr. Fleuss for his kind permission to bring his improvements before the notice of the Institution.

In conclusion the author may perhaps allude to the use of the Electric Light for submarine purposes. This is really the only light which can be of use to the diver, and of late the author has made some very satisfactory trials of it. The Telephone has not been fully tested in practice, the divers preferring their ordinary signal line, or communicating by a slate.

Abstract of Discussion on Diving Appliances.

Mr. Gorman exhibited a complete diving helmet, and other appliances. He wished to add that since the paper was written (now some months ago) Mr. Fleuss had had his apparatus in actual practice. Not long since he had saved ten lives in the Killingworth colliery; and he had also used his apparatus at the opening out of the Maudlin seam in the Seaham colliery.

Mr. Henry A. Fleuss showed the action of the apparatus, Plate 26. He explained that the apparatus was put on, the mouth piece hung round the miner's neck by the elastic fastener, and the eye protector carried by putting the arm through the fastener; and in that condition he went into the pit. The eye protector and mouth piece could be adjusted in a moment in case he came suddenly into foul gases. (In Figs. 17 and 18 the mouth piece and eye protector are combined in one, forming a mask.) By putting his hand behind him and turning the tap T, he could at any time get more air from the reservoir D; and this had to be done every ten minutes. This air was pure oxygen admitted from the reservoir D to the bag G, which held 300 or 400 cubic inches. He could if he chose make the man breathe only the proper mixture of oxygen and nitrogen, by first inflating the bag with exhaled breath, before connecting the breathing tubes, and by simply keeping up a constant supply of oxygen to take the place of that absorbed by the lungs and that abstracted in forming carbonic acid. But that was a dangerous practice; if the man got a considerably less amount of oxygen than was contained in the natural air he would drop insensible, and if not relieved would die. By the arrangement he had explained everything was perfectly safe, because as long as there was any air in the bag it would contain sufficient oxygen; and whenever the man found the *volume* in the bag was not sufficient, he could put his hand to the tap and admit more. The proportion, he believed, was about one-third oxygen to two-thirds atmospheric air, or perhaps rather smaller. If common air were admitted to the bag instead of oxygen, under the same conditions as to absorbing the carbonic acid gas, the man would go on breathing a higher and higher percentage of nitrogen without knowing it, and suddenly, when the oxygen was nearly gone, he would drop down insensible; but, in consequence of being able to continue inhaling a full breath, he would never feel the deficiency of oxygen until it was too late.

The carbonic acid remained of course in the filter, forming carbonate of soda, and the volume of gas thus abstracted was made up by the oxygen. He had made an improved filter, since the paper

was written, in which, instead of india-rubber sponge, he was simply using tow, with caustic soda sticks. This formed an efficient filter; and when the soda was completely carbonised, the whole could be thrown away. The sponge cost a sovereign, but a halfpenny worth of tow was sufficient for the same purpose.

Mr. Jeremiah Head asked what was the composition of the air that came back into the bag from the filter, and was used over again; and also what was the object of the short piece of pipe attached to the side of the eye protector.

Mr. Fleuss said the exhaled air contained less oxygen than when inhaled, the same nitrogen, and a comparatively large proportion of carbonic acid, of which the carbon was supplied from the lungs. The *whole* of the carbonic acid was absorbed by the filter; so that what came back to the bag was atmospheric air, minus a certain quantity of oxygen, a part of which remained in the filter in the form of carbonate of soda, while a small part was absorbed by the lungs. He had used the apparatus, in actual work at the Seaham colliery, for an hour and a half at a time, and for experimental purposes much longer. The short piece of india-rubber tube on the eye protector was simply for inflating with the mouth the air-cushion in the eye-plate, in order just to make an air-tight joint for the face, when working in foul gases which might injure the eyes.

Mr. Charles Cochrane said that, with regard to the application of diving apparatus generally to mining, he could bear testimony to the admirable and prompt way in which work could be carried out, even in the provinces. His firm recently lost a lift of trees in a colliery in South Staffordshire, and the only chance of preventing disaster was to get a diver at work at once. They lost the lift about four o'clock in the afternoon, and telegraphed at once to London for an apparatus to be brought down similar to that which had been described; and they were at work again on the following day, within twenty-four hours of the accident.

Mr. Druitt Halpin said he had used the author's diving apparatus with great success on several occasions, and could speak very highly of it, and also of the men who worked it; it was no use having the best apparatus in the world unless there were suitable men for working it. Of all workmen he would give the palm to divers for causing trouble, if they were not kept under proper control; but when they were under proper control a very good amount of work could be got out of them. There was one point with regard to the helmet that he thought might be improved. The glass shield in front had to be taken off when necessary to speak to the man, and then put on again. It was an awkward job at the best of times, and it was made more awkward by the buttons for unscrewing being solid knobs; if these were made like a common winch-handle, and then milled, they would give a chance of doing what was wanted, without doing what was not wanted, but sometimes happened, namely dropping the shield overboard.

Mr. Charles Hawksley said that some few years ago he had had occasion to repair a pump which had failed in a well of small diameter, put down temporarily to enable a larger shaft to be sunk at some waterworks in Lancashire. In that confined situation one of the parts of the pump gave way, and the only means of getting at it to do the necessary repairs was by means of divers. A diver was sent down by the author's firm, and although the well was crowded with pump trees and their means of support, he descended to a depth of 130 ft., and in that depth of water he successfully replaced the broken part; so that the pump was able to be set to work again with comparatively little delay. He had also employed divers very recently to assist in laying two lines of gas and water pipes across the harbour at Lowestoft. Those pipes were laid in a trench, that had been dredged in part by Mr. Langley's dredger described at the last meeting (Proc. 1882, p. 100). After the trench had been ascertained, by means of the divers, to be perfectly level, the pipes were lowered; and it was then necessary, in order to clear the harbour, to cut away all the tackle by which they had been lowered—the chains, blocks, &c.—and let it fall to the bottom of the harbour. A diver afterwards went

down and recovered the whole of the tackle, and ascertained at the same time that the pipes had been properly laid.

With regard to the admirable invention of Mr. Fleuss, he might be permitted to refer to the paper which his friend Mr. Marten and himself had the honour of presenting to the Institution in 1877 (Proceedings, p. 314) on the means to be employed for preventing or alleviating accidents at mines. Certainly, had this apparatus been invented at that time, it would have found a place in the list of appliances which they deemed it desirable should be kept in readiness at collieries, or in some situations where they could be obtained for use in case of need. The author had not referred to the model exhibited of a diving bell, which had been manufactured by Messrs. Siebe and Gorman, and employed at Barbadoes.

Mr. Gorman said he had not meant to do more than show the model of the bell, as he hoped to give a subsequent paper on appliances for excavating under water and for the removal of sunken rocks. The bell had an air-lock with two doors or valves, made to slide backwards and forwards in grooves. There was also a regulating valve, so as to equalise the pressure between the lock and the top or bottom as required. The bell was mostly used for laying concrete blocks or removing quantities of rock. When the bell was lowered, the pressure of the air kept the water to within four inches of the bottom, or on level ground within half an inch of the bottom, the men working with water boots. They had made an arrangement of stuffing-boxes, to bring down a tube for working one of Ingersoll's rock drills at the bottom, so that the work was done quickly. When the blasting holes had been charged and tamped, a signal was given by means of a wire to a gong at the surface. The man in the barge then placed to his ear the small speaking tube, having a diaphragm of thin copper, and listened to the instructions of the divers which way to move the bell. The bell was then moved away, and the charge was fired; then the bell was brought back again, and the *débris* cleared away through the air-lock. There was also an arrangement by which the top of the chamber was filled with water

for ballast; and by turning a valve this water could be expelled by the air pressure, so as to make the bell almost float.

The depth at which the bell generally worked was 30 feet; but rings could be put on the internal tube, so that it might be lengthened as required, when the depth varied. The diameter of the tube was $3\frac{1}{2}$ feet, and that of the exterior chamber 14 feet. The bell was weighted at the bottom with cast-iron ballast, which could be removed, if required, through a man-hole. In each of the air-lock doors there was a lens, so as to let a certain amount of light down into the bell; but candles had also to be used.

He exhibited one of the electric lamps made for the Admiralty, for use under water in torpedo or other work; it was the only light of any use under water. It was a differential lamp, the whole apparatus being at the top, while if there was any leakage of water it would lie in the bottom. The lamp threw out a very powerful light, equal to 1500 candles, and one could read print plainly within six feet from the lamp; but beyond that distance the light was very much diffused and lost, and became only sufficient for the men to grope their way by. It must be understood he alluded to night work in clear water.

Mr. E. A. Cowper asked if the light attracted the fish very much. He enquired because he had proposed some time ago to fish with the electric light, having a small net below the lamp to haul up at intervals, and so catch the fish.

Mr. Gorman said he had had some letters from Norway upon the same subject, and there they proposed to use the electric light for that purpose. When he had been down himself with a new and bright helmet on, he had seen quantities of fish swimming round it. Apparently anything bright attracted them.

Mr. Halpin said it was easy to get rid of any difficulty connected with fish coming in the way of the electric light, by ejecting a small quantity of paraffin oil into the water round the lamp, which at once drove the fish away.

Mr. E. B. Marten said that in South Staffordshire he had several times made the author's diving apparatus useful for liberating old lifts, in shafts where they could not be disentangled from above. The men went down to very great depths—say 110 feet; and it was a most remarkable thing how, even where they had to go down a most entangled shaft and in a strange pit, the men ventured down in total darkness, feeling their way about. One of the men even said he would rather have no light; and, although he had to go amongst all sorts of timber &c., he felt his way carefully down, and came up again in a few hours after accomplishing all that he had to do.

Mr. Charles Hawksley said that Mr. Gorman had omitted to explain one interesting point in the diving bell. In some cases accidents had occurred through the turning over of the bell, when allowed to rise to the surface: owing to accidental canting of the bell, the water ballast rushed to one side, and turned it over, and the men were drowned. In the bell in question provision was made to prevent such an accident; because the ballast chamber was divided by a horizontal partition, so that, supposing the bell rose suddenly and canted, the water below the partition would not rush to one side, but would be held in place by the partition. He did not wish to imply that the contrivance was an original one. It had been previously used in connection with torpedo work.* Again, in the Proceedings of the Institution of Civil Engineers, vol. xxxvii., p. 339, there was an account of Mr. B. B. Stoney's great diving-bell, by which the North Wall at Dublin was extended, and which was being used at the present day for lowering his 300-ton blocks of walling. That bell was 16 feet square at top and 20 feet square at bottom, and weighed 80½ tons; it had the same arrangement as to the air lock, but not as to the water ballast.

Mr. Fleuss said that in working in pits it was utterly impossible, although his apparatus was complete for breathing, to work without a light; and where the gases were so dense that the men could not breathe them, it was necessary to have some special kind of lamp. He

* See also Proceedings Inst. M. E., 1867, Plate 19, Fig. 22, and pages 94–5.

exhibited a lamp (Plate 27) which he had designed for the purpose, and which he had frequently carried, when working in the Maudlin seam at Seaham. It was a modification of the lime light. The lower part A of the lamp (Fig. 20) contained the oxygen under a pressure of 16 atmospheres, while the hydrogen was supplied from methylated spirits of wine, contained in the cylinder B, to a burner C, fed by two wicks. Between these wicks a stream of oxygen was made to play through a small jet D upon a cylinder of lime E, held on a stud placed to receive it. There was thus a jet of oxygen burning in an atmosphere of hydrogen, which he believed was a novelty in lamps. The sphere A was charged with oxygen, when required, through the valve I. The stream of oxygen was regulated by a jamb-screw valve F attached to the oxygen chamber. The upper part or cover G of the lamp was a double casing, and the annular space between the two casings was nearly filled with water. There were double glasses HH, one in each casing, and the water circulated between them. The products of combustion escaped through a valve J at the lower part of the casing into the annular space filled with water, through which they bubbled up, and finally escaped through an outlet valve O at the top. A valve was placed here, merely in order to prevent any dirt from getting into the water and so obscuring the light; the lamp burned equally well with or without the valve. The cover was secured by a leather washer and screw joint, and the lamp was carried by a handle K. After the lamp had been burning about a quarter of an hour, about a quarter of an inch additional depth of water would be formed in the casing by the combustion of the hydrogen and oxygen. This was also a great element of safety, as it made a water sealed joint. The lamp had been used at the Seaham colliery with great success, and the men were frequently able to see to work at a distance of 40 yards from the lamp, which showed the power of the light. The lamp would burn in any explosive gases or under water. He had used it night and day for five weeks at the opening of the Maudlin seam, which was full of explosive gas. The lamp now exhibited, with a 7-in. sphere, would burn four hours; and one with a 10-in. sphere would he thought burn twelve hours, but that would increase its weight from 12 lbs. up to 15 or 16 lbs.

He might be permitted to say further that, if the breathing apparatus and the lamps were kept ready at every colliery, they would often, he believed, be the means of saving human life and property. At the Killingworth colliery, mentioned by the author, one of the men who had been rescued had since died from exhaustion; but the apparatus that was used there had to be obtained from another colliery at a considerable distance, and had it been on the spot he was certain that the men would all have been got out alive, and no deaths would have occurred subsequently.

Mr. Charles Cochrane said it would be interesting to know how the reservoir of the breathing apparatus could be promptly charged with oxygen, so as to ensure that there should be no mistake as to its use when required.

Mr. Fleuss said the vessel could be kept charged for any length of time, by using common precautions in shutting off the valve. It could be easily seen at any time whether the valve was properly shut, by putting a film of moisture across the hole, when in an instant it would be seen if gas was leaking even to the smallest extent, by the bubbling of the film. To ensure a sufficient supply of the oxygen gas, it might be carried in an iron store cylinder, containing 30 cubic feet under a pressure of 600 lbs. to the square inch. A connection could be made from this to the breathing apparatus by a flexible india-rubber tube capable of standing the pressure; and with the aid of a pressure gauge the reservoir could be charged to 240 lbs. or 260 lbs. pressure. Apart from that plan, it was very easy to make oxygen gas. All the theatres made it for their lime lights, and he himself left a complete set of gear for making it at the Seaham colliery, after working there for five weeks. It comprised a mercury bottle converted into a retort, with a pipe attached. There were two purifying vessels containing simply water—changed as often as was desired—to wash the chlorine out of the gas. There should be two or three bags to hold the gas as it was made: and in twenty minutes you could get off enough gas to charge one breathing machine, and in a few minutes longer enough to charge several more. Small

handy compressing pumps were made to force the oxygen into the breathing machines or lamps. He had used such an apparatus all the time he was at Seaham, keeping two or three store bottles in reserve, in case of the pump breaking down, which it did once or twice from the great strain put on it, and from the firing of the leathers. They were working day and night with six lamps and six breathing machines; and these were constantly being brought up, refilled, and taken down again.

Mr. Jeremiah Head asked what was the cost of the whole apparatus, and whether there was any difficulty in getting the miners to use it.

Mr. Fleuss said, roughly speaking, the cost was £18 for the breathing machine, and £13 10*s.* for the lamp. There was no difficulty in getting the men to use the apparatus, except when they first had to put on the mask, and go into a pit the conditions of which they knew nothing about, and where there were gases that would kill them if unprotected; then they might perhaps feel a little nervous. At Seaham they put up a wooden building at bank, filled with sulphur fumes, so as to give the men two or three days' practice. He found plenty of volunteers for that, but for going down the pit itself the numbers were considerably reduced. There were however half a dozen first-class men who went in fearlessly, and were ready at any time. Some of these men afterwards went down the Killingworth colliery, and were the means of rescuing several lives.

The President said that he was glad to inform the meeting that Lieut. Stanley Dean-Pitt, R.N., had been good enough to be present on this occasion, having come expressly from Portsmouth, to give them the benefit of his experience in the diving operations carried on at the wreck of the *Doterel.*

Lieut. Dean-Pitt said all subjects connected with engineering were of great interest to naval officers. At the present day it was absolutely necessary for a naval officer to know something about

engineering; and he might mention, as a proof of the change which was going on in the service, the pleasure they had had the other day in hailing the appointment as a Lord Commissioner of the Admiralty of that eminent and practical engineer Mr. George Rendel. Submarine engineering had always been to himself a subject of keen interest, and some years ago he was fortunate enough to have the opportunity of practically learning to dive. This had proved of great service to him lately, when the terrible disaster occurred at Sandy Point, Magellan Straits, in which H.M.S. *Doterel* was totally destroyed, and 140 men and officers killed. H.M.S. *Garnet*, to which he belonged, was then on the South-East coast of America, and received telegraphic orders from the Admiralty to proceed at once to the scene of the accident. On arrival there, after a few preliminary matters had been settled, they went to work. The wreck was lying in 12 fathoms, or 72 ft.; and, the water being comparatively clear, George Hunt, an artificer diver, and himself were able to make a very careful survey of every part of the wreck.

He would not dwell upon the many awful sights that met their view; but some idea might be formed of how things were when he stated that, out of the 140 men who were killed, there were only twenty whole bodies, the remainder being in pieces. Of the whole bodies one was that of his old friend and shipmate Lieut. Creagh, who was sitting in an arm-chair under the poop just as if he were asleep, and without a mark on him—perfectly uninjured, as far as outward appearances went. The ensign was half-mast high, looking as if it was mourning for the killed; and he hoisted it up again, as he did not care to go about his work under a half-mast flag. The system of their work was this. They commenced at daylight, which was at 7.30 in the morning, and worked until dark, between 4.30 and 5. They generally used to stop for an hour in the middle of the day, at 12 o'clock. They worked under water two to three hours at a spell, and then came up for ten minutes or a quarter of an hour, and went down again. They worked every day for five weeks, Sundays included. On the average four men, namely three divers and himself, were at work all the time; and they recovered the whole of the ship's armament, including six heavy guns and two

machine guns, her anchors, chain cables, spars, yards, and a variety of other things which it was needless to enumerate. After they had been at work some time, with a good deal of difficulty the artificer diver and himself succeeded in reaching the boilers; they were able to make a careful examination of them, and thus to decide that most important question, whether they had exploded or not. They were intact. They also entered and very carefully examined the bunkers; and there had never been any doubt in their minds that these also had never exploded.

He desired to congratulate the author upon the great efficiency of the apparatus described in the paper. If it had not been most perfect, he himself should not have had the pleasure of being present on this occasion; because one day, when they were looking after the boilers, he was standing on some wreckage, when it gave way, and he was thrown head downwards into a hole, where he was firmly fixed and perfectly helpless. As far as he knew, he might have been there still; but the artificer diver saw him and came at once to his help. He could not get to him, but he paid a rope down into his hands; and he (Lieut. Dean-Pitt) then twisted it round the neck of his helmet, and after some minutes the diver managed to haul him up feet foremost, the apparatus remaining uninjured. He thought that, if anything ever proved the efficiency of the apparatus, it was that incident: at least it proved it to him.

With regard to the open helmet, described p. 182, he was very thankful it had been so much improved upon; for if he had been wearing an open helmet on the occasion mentioned, he must undoubtedly have been drowned. He thought the fact that he himself and three men had worked continuously for five weeks at a depth of 12 fathoms, on a broken wreck covered with debris of every description, and in intensely cold water, without a single accident of a serious nature, was a conclusive proof of the very great efficiency and perfection of the apparatus in question. He was very glad to hear that the author had tested the submarine electric light, which would be undoubtedly a very valuable help in diving operations. He should like to hear also whether the author had tested the telephone for the use of divers; because at the wreck of the *Doterel*, where the water was

intensely cold, there being over a foot of ice on shore, it was quite impossible to do such a delicate thing as to write legibly upon a slate. They could read what was sent down to them, but they could never answer, or only rarely, in writing. If they had had a telephone, it would have been invaluable, and would have saved a great deal of time and labour.

Mr. Wm. Anderson asked what temperature there was inside the diving dress. He imagined it must be tolerably high, if they could remain long under water so cold. He also wished to know what degree of light there was at the depth they worked at, and how far they could see.

Lieut. Dean-Pitt said the temperature inside the dress depended entirely upon how they were working. If they worked hard, the temperature got very high; and they sometimes had to rest a few minutes to get cool. But what they suffered from chiefly was the intense cold to their hands. With regard to the light, the water was very clear indeed, clearer than was usual close to the land; and they could very fairly distinguish what a thing was at a distance of 7 or 8 feet, though they could not see its parts distinctly.

Mr. Gorman, in reply, said Mr. Halpin had suggested a slight improvement in the knobs for screwing up the front eye-glass. He thanked Mr. Halpin for the suggestion, which would be of great assistance in screwing up the glass when the hand was cold. He had tried fixing the front eye or screw lens by a hinge joint, but had found it did not work satisfactorily. Another gentleman, Mr. Schönheyder, had suggested to him privately the arranging of the glass with a segment like the neck screw, so that it could be unscrewed by one-eighth of a turn. They had tried that, but the divers objected to it; because when a man was in a confined position, for instance between decks discharging cargo, if anything happened to strike the glass as he was moving, it might possibly get unscrewed by the one-eighth of a turn, and drop out, and then the man would be drowned. Perhaps however, where men were

simply laying concrete blocks, or in places free from danger, the plan might be useful.

Mr. Cochrane had kindly referred to the efforts made in sending off some men to his pits about ten days back. They had been sent off in two hours after receiving the telegram, and in twenty-four hours they had completed the work allotted to them, thereby preventing a serious disaster. They had done the same thing on several occasions, for Mr. Marten and others. It was true that the men preferred to work without artificial light. They became actually like blind men; the sense of feeling became very acute, and working from day to day as they did they became wonderfully quick at the work they had to perform. In the case of the wreck of the s.s. *Caledonian* the men actually took the engines to pieces under water, and sent them up; also the boilers; and that was done in total darkness.

With regard to the air-lock diving bell, Mr. Stoney's great bell, used in 1871, was somewhat different in construction from the one now exhibited, being of cast-iron, in sections bolted together; whereas the bell represented by the model was made of wrought-iron, the upper chamber of $\frac{3}{8}$ in. and the lower of $\frac{1}{2}$ in. plate. It was also provided with a water-ballast chamber, as described by Mr. Hawksley. But he was indebted to Mr. Stoney for very valuable hints, having been in correspondence with him during the time he was constructing the bell for Barbadoes.

With reference to the uses of the diving apparatus at the present time, the Admiralty now attached so much importance to the subject that they had established two classes for training divers, one at Portsmouth and the other at Devonport, and they had annually from eighty to ninety divers trained for the service. The Royal Engineers also had classes formed, at Chatham; the men were trained in the Medway, and they also went to dive off Sheerness, where they got into deep water. The Royal Engineer officers were likewise urged to dive. In the Navy the officers could learn diving if they chose to do so; and they had just heard an instance of the value of that system, because Lieut. Dean-Pitt's examination of the wreck was most valuable to the Admiralty when he was summoned home to give evidence at the Court Martial. Again the

value of the sponge imported into this country each year amounted to £90,000, and that was mostly obtained by helmet divers. Lately the pearl fisheries in the Torres Straits had also become very extensive; a schooner had arrived home a short time ago with a very valuable cargo which had been fished up in six weeks, and which realised £8,000. There were now a number of vessels fitted out for that purpose. Altogether therefore the apparatus was being developed in other directions besides harbour works and wrecks, where it was absolutely necessary. Actual experience had proved the necessity of having one or two divers on board each of our war ships; and on board our large merchant steamers they would be equally useful. The Telegraph Construction Co., as also Messrs. Siemens, carried divers on board their cable ships. Much detention and loss of time and money might be prevented, and even the loss of many valuable ships and lives, if a diver were always at hand to lend his services when required. Feeling the necessity for this, he had brought out a small portable diving apparatus, occupying little room, and costing only £40; and at his works he had a large diving tank 12 feet deep, where steamship owners could have one of their engineers or ship carpenters trained. He might mention a case in point. One of his men was proceeding to the Sydney Exhibition on board the *Poonah* P. and O. steamer, when her propeller became loose on the shaft while steaming against a gale in the Red Sea. The necessary repairs were done by the diver, and the voyage was resumed, preventing considerable loss of time and money.

With regard to the telephone, he had been carrying out a number of experiments with that instrument, and had made it very perfect. At present, if two divers under water placed their helmets together, they could hear one another converse. But with the new instrument, if two divers placed their helmets together, the men at the surface could hear what the divers were talking about. He hoped to exhibit this on a future occasion. As the services of divers were now required for so many various operations, it was necessary to equip the men with every possible contrivance, so that they could work without danger, and with such confidence as should enable them to do credit to themselves and give satisfaction to their employers.

ON POWER HAMMERS WITH A MOVABLE FULCRUM.

By Mr. DANIEL LONGWORTH, of London.

The Movable-Fulcrum Power Hammer was designed by the writer about $5\frac{1}{2}$ years ago, to meet a want in the market for a power hammer which, whilst under the complete control of only one workman, could produce blows of varying force without alteration in the rapidity with which they were given. It was also necessary that the vibration and shock of the hammer-head should not be transmitted to the driving mechanism, and that the latter should be free from noise and from liability to derangement. The various uses to which the movable fulcrum hammers have been put, and their success in working*—as well as the importance of the general subject which includes them, namely the substitution of stored power for human effort—form the author's excuse for now occupying the time of the meeting.

Until these hammers were introduced, no satisfactory method had been devised for altering the force of the blow. The plan generally adopted was to have either a tightening pulley acting on the driving belt, or a friction driving clutch, or a simple brake on the driving pulley, put in action by the hand or foot of the workman. Heavy blows were produced by simply increasing the number of blows

* The hammers have been for some years used by Mr. A. C. Bamlett of Thirsk, the American Tool Co. of Antwerp, Messrs. W. and T. Avery of Birmingham, Pullar and Sons of Perth, Salter and Co. of Westbromwich, Vernon Hope and Co. of Wednesbury, &c. &c.; and also for stamps by Messrs. Collins and Co. of Birmingham, &c.

per minute (and therefore their velocity), and light blows by diminishing it—a plan which was quite contrary to the true requirements of the case. To prevent the shock of the hammer-head being communicated to the driving gear, an elastic connection was usually formed between them, consisting of a steel spring or a cushion of compressed air. With the steel spring, the variation which could be given in the thickness of the work under the hammer was very limited, owing to the risk of breaking the spring; but with the compressed-air or pneumatic connection, the work might vary considerably in thickness, say from 0 to 8 in. with a hammer weighing 400 lbs. The pneumatic hammers had a crank, with a connecting-rod or a slotted cross bar on the piston-rod, a piston, and a cylinder which formed the hammer-head. The piston-rod was packed with a cup leather, or with ordinary packing; the latter required to be adjusted with the greatest nicety, otherwise the piston struck the hammer before lifting it, or else the force of the blow was considerably diminished. As the piston moved with the same velocity during its upward and downward strokes, and, in the latter, had to overtake and outrun the hammer falling under the action of gravity, the air was not compressed sufficiently to give a sharp blow at ordinary working speeds, and a much heavier hammer was required than if the velocity of the piston had been accelerated to a greater degree.

As it is impossible in the limits of this paper to describe all the forms in which the movable-fulcrum hammers have been arranged, two types only will be selected, taken from actual work; namely a small planishing hammer, and a medium-sized forging hammer.*

The small planishing hammer, Figs. 1 and 2, Plate 28, is used for copper, tin, electro, and iron plate, for scythes, and for other thin work, for which it is sufficient to adjust the force of the blow once for all by hand, according to the thickness and quality of the material, before

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* To the makers, Messrs. W. and J. Player (late Messrs. J. Scott Rawlings and Co.) of Birmingham, the author is indebted for the working drawings of these hammers.

commencing to hammer it. The hammer weighs 15 lbs., has a stroke variable from $2\frac{1}{2}$ in. to $9\frac{1}{2}$ in., and makes 250 blows per minute. The driving shaft A is fitted with fast and loose belt-pulleys, the belt fork being connected to the pedal P, which, when pressed down by the foot of the workman, slides the driving belt on to the fast pulley and starts the hammer; when the foot is taken off the pedal, the weight on the latter moves the belt quickly on to the loose pulley, and the hammer is stopped. The flywheel on the shaft A is weighted on one side, so that it causes the hammer to stop at the top of its stroke after working; thus enabling the material to be placed on the anvil before starting the hammer. The movable fulcrum B consists of a stud, free to slide in a slot C in the framing, and held in position by a nut and toothed washer. On the fulcrum is mounted the socket D, through which passes freely a round bar or rocking lever E, attached at one end to the main piston F of the hammer G, and having at the other extremity a long slide H mounted upon it. This slide is carried on the crank-pin L, Fig. 2, fastened to the disk M attached to the driving shaft A. The crank-pin, in revolving, reciprocates the rocking lever E and main piston F, and, through the medium of the pneumatic connection, the hammer G. The slide H, in revolving with the crank-pin, also moves backwards and forwards along the rocking lever; and it will be seen that it is nearer the fulcrum B during the down-stroke of the hammer, than it is during the up-stroke. By this means, the leverage being shortened, the velocity of the hammer is considerably accelerated in its downward stroke, causing a sharp blow to be given; whilst it is more gently raised by the increased leverage during its upward stroke.

To alter the force of the blow, the hammer G is made to rise and fall through a greater or less distance, as may be required, from the fixed anvil-block K, after the manner of a smith giving heavy or light blows on his anvil. It is evident that this special alteration of stroke could not be obtained by altering the throw of a simple crank and connecting-rod; but by placing the slot C parallel with the direction of the rocking lever E when the latter is in its lowest position, the hammer then resting on the anvil and the crank being at the top of its stroke, this lowest position of the rocking lever

and hammer is kept unaltered, no matter what position the fulcrum B may have in the slot C. To obtain a short stroke, and consequently a light blow, the fulcrum is moved in the slot towards the hammer G; and to produce a long stroke and heavy blow the fulcrum is moved in the opposite direction.

Figs. 3 and 4, Plate 28, give the details of the pneumatic connection between the main piston and the hammer, whereby packing and glands are dispensed with. The hammer G is of cast steel, bored out to fit the main piston F, the latter being also bored out to receive an internal piston J. A pin I, passing freely through slots in the main piston F, connects rigidly the internal piston J with the hammer G. When the main piston is raised by the rocking lever, the air in the space X, between the main and internal pistons, is compressed, and forms an elastic medium for lifting the hammer; when the main piston is moved down, the air in the space Y, between the piston and hammer, is compressed in its turn, and the hammer forced down to give the blow. Two holes H H drilled in the side of the hammer, Fig. 4, renew the air automatically in the spaces X and Y, at each blow of the hammer.

Figs. 5, 6, and 7, Plate 29, represent the medium-size forging hammer, for making forgings in dies, swaging and tilting bars, and plating edge-tools, &c.

The hammer weighs 1 cwt., has a stroke variable from 4 to $14\frac{1}{2}$ inches, and gives 200 blows per minute; the compressed-air space between the main piston and the hammer is sufficiently long to admit forgings up to 3 in. thick under the hammer.

To make forgings economically, it is necessary to bring them roughly into the desired form by a few heavy blows, whilst the material is still in a highly plastic condition, and then to finish them by a succession of lighter blows. The heavy blows should be given at a slower rate than the lighter ones, in order to allow time for turning the work in the dies or on the anvil, and so to avoid the risk of spoiling it. In forging with the steam-hammer the workman requires an assistant, who, with the lever of the valve motion in hand, obeys his directions as to starting and stopping, heavy or light blows, slow or quick

blows, etc.; the quickest speed attainable depending on the speed of the assistant's arm. In the movable-fulcrum forging hammer, the operations of starting and stopping, and the giving of heavy or light blows, are under the complete control of one foot of the workman, who requires therefore no assistant; and, by properly proportioning the diameter of the driving pulley and size of belt to the hammer, the heavy blows are given at a slower rate than the light ones, owing to the greater resistance which they offer to the driving belt.

In this hammer the pneumatic connection, the arrangements for starting, stopping, and holding up the hammer, as well as those for communicating the motion of the crank-pin to the hammer by means of a rocking lever and movable fulcrum, are similar to those in the planishing hammer; differing only in the details, which provide double guides and bearings for the principal working parts.

The movable fulcrum B, Fig. 6, consists of two adjustable steel pins, attached to the fulcrum lever Q, and turned conical where they fit in the socket D. The fulcrum lever is pivoted on a pin R fixed in the framing of the machine, and is connected at its lower extremity to the nut S, in gear with the regulating screw T. The to-and-fro movement of the fulcrum lever Q, by which heavy or light blows are given by the hammer, is placed under the control of the foot of the workman, in the following manner. A double-ended forked lever U, Figs. 5 and 6, pivoted in the centre, embraces at one end the starting pedal P, and at the other end the small belt which connects the fast pulley on the driving shaft A either with the loose pulley Y, or with one of the reversing pulleys W and X. These latter drive, through ordinary bevel reversing gear, the regulating screw T in connection with the fulcrum lever Q. When the workman places his foot on the pedal P to start the hammer, he finds his foot within the fork of the lever U; and by slightly turning his foot round on his heel he can readily move the forked lever to right or left, so shifting the small belt on to either of the reversing pulleys W or X, and causing the regulating screw T to revolve in either direction. The fulcrum lever is thus caused to move forwards or backwards, so as to give light or heavy blows. By moving the forked lever into mid position, the

small belt is shifted into its usual place on the loose pulley Y, and the fulcrum B remains at rest. To fix the lightest and heaviest blow required for each kind of work, adjustable stops are provided, and are mounted on a rod N, Fig. 6, connected to an arm of the forked lever U. When the nut of the regulating screw T comes in contact with either of these stops, the forked lever is forced into mid position, in spite of the pressure of the workman's foot, and thus further movement of the fulcrum lever, in the direction which it was taking, is prevented. The movable fulcrum can also be adjusted by hand to any required blow, when the hammer is stopped, by means of a handle at V in connection with the regulating screw T.

In conclusion the author wishes to direct attention to the fact, that in many of our largest manufactories, particularly in the Midland counties, foot and hand labour for forging and stamping is still employed to an enormous extent. Hundreds of "olivers," with hammers up to 60 lbs. in weight, are laboriously put in motion by the foot of the workman, at a speed averaging fifty blows per minute; whilst large numbers of stamps, worked by hand and foot, and weighing up to 120 lbs., are also employed. The low first cost of the foot hammers and stamps, combined with the system of piece work, and the desire of manufacturers to keep their methods of working secret, have no doubt much to do with the small amount of progress that has been made; although in a few cases competition, particularly with the United States of America, has forced the manufacturer to throw the oliver and hand-stamp aside, and to employ steam or power hammers and stamps. The writer believes that in connection with forging and stamping processes there is still a wide and profitable field for the ingenuity and capital of engineers, who choose to occupy themselves with this minor, but not the less useful, branch of mechanics.

Abstract of Discussion on Power Hammers with Movable Fulcrum.

Mr. A. C. Bamlett said he had taken the first hammer of that type that was ever sold, having confidence in the principle, although it differed so much from the hammers in ordinary use. He had had it in use for several years. It gave no trouble, and he had found it very useful. The smiths appreciated it, and the strikers never did any work that the hammer could do. The fulcrum arrangement appeared to work well, and the hammer had not given more trouble than any other tool in the shop.

Mr. David Joy had had a good deal to do with steam-hammers of various sorts, including power-hammers; and there was one piece of experience he should like to mention, and to ask Mr. Longworth if he could corroborate it. He had built a good many small hammers for making horse-shoe nails. These were in two sizes—28 lbs. and 56 lbs.; and they were worked by a piston in a cylinder, the piston-rod being like a steam-hammer of large diameter coming out below the cylinder. Between the piston and the bottom of the cylinder there was an air-cushion, by which the blow was regulated. The hammer was driven by a horizontal bar or lever, which took hold of the piston at one end, had its fulcrum at the other end, and was taken hold of in the middle by a link worked from a small eccentric, which moved the lever up and down. His great difficulty lay in making this lever stand the work. He tried all conceivable materials, ending with steel. He tried a thin plate of steel, and he tried a thick plate; and then he tried steel springs, which cost thirty shillings each; but nothing would stand. At last he put in a bar of ash-wood that cost three shillings, and found it would stand twenty times as long as the steel springs. He should be glad to know whether Mr. Longworth had found any similar difficulty with the rocking lever E, Figs. 1 and 6, Plates 28 and 29, which transmitted the power from the crank-pin to the hammer—whether the jar of the blow caused it to suffer. He did not think there could be the least trouble with the

piston or any other parts of the machinery. The question with him was whether the elasticity of the air in the two spaces X and Y, Figs. 3 and 4, so took away the shock from the rest of the machinery as to protect the lever E from damage.

Mr. J. J. Smyth said the question of steam-hammers or power-hammers rather presented itself to his mind as a matter of economy. It was known that small steam-hammers were apt to waste a great deal of steam; at the same time you could frequently lead a steam-pipe where you could not so easily lead a length of shafting, and there was also the power expended in driving the shafting when the hammer was at rest. But then the question arose as to the relative wear and tear. A small ½-cwt. steam-hammer of good make would work perhaps five or six years, and not cost more than ten shillings a year (which was simply for new piston-rings and wearing parts) to keep it in order. Mr. Longworth could most likely give some information as to the comparative wear and tear in the kind of power-hammer now described. His own firm had two steam-hammers, one ½-cwt., and one 1½-cwt. The 1½-cwt. hammer, used for making axles, had been at work for twelve years, and the smaller hammer nearly eight years; and the joint expense in repairs during that time had been £11 5*s*., which he thought showed great economy. The cylinders had not required re-boring, and the only expense they had involved was for new piston-rings, radius levers, and rollers. Provided a power-hammer of the class now shown could work with equal economy, it would be decidedly preferable to the steam-hammer, because in the steam-hammer there was a considerable waste by condensed steam.

Mr. A. Paget wished to ask a question as to the statement, p. 208, "the heavy blows are given at a slower rate than the light ones, owing to the greater resistance which they offer to the driving belt." He presumed what was really implied by this was that the driving belt slipped with the heavy blows. If so, surely that meant a heavy wear of the belt, and a great loss of power. He should like to ask whether any particulars could be given as to the rate at

which the belts wore out, and whether the power lost was great. Of course with some of the hammers the occasions on which the slow heavy blow was wanted were few, and there the trouble would not be great. But in ordinary smith's forging a slow heavy blow would be wanted often; and there the wear of the belt would, he thought, be considerable.

Mr. S. Z. Lloyd asked whether the hammer had been used for forging bolts or rivets, as a substitute for an oliver.

Mr. Longworth in reply said, with reference to Mr. Joy's remarks about the strain upon the rocking lever, his own hammer was entirely different from the arrangement Mr. Joy had used, because in the latter the lifting bar was connected direct with the hammer, and thus partook of its vibration. In his own hammer, and indeed in all pneumatic hammers, the shock was entirely prevented from reaching the driving mechanism. You could put your hand on the rocking bar while the hammer was in motion, and although the anvil &c. trembled with the vibration, you could not feel the slightest motion in the bar, except the regular up and down swing. Of course in that case there was no tendency to break, and not one of those bars had broken since the hammers had been in use. As to the wear and tear of the pistons, he did not think there was anything to be feared with regard to that point, the motion being quite vertical, and the bearing surfaces being very long, and in a good position for getting lubricated; in fact they were kept constantly supplied with oil. There had never been any trouble with them. In the first hammers constructed, it had been thought necessary, simply from custom, to put in piston rings; but afterwards they were entirely dispensed with, and there were no rings in the hammers now made.

With reference to the driving belt, there was of course some slipping, as Mr. Paget had suggested, and if that were continued very long it would have a wearing effect upon the belt; but it was only occasional, for it was only when the hammer was wanted to go slow, for one or two heavy blows at the commencement of a forging,

that any slip took place. No practical inconvenience had been felt with regard to that point.

The hammers had not been used for forging small bolts and nuts, or for rivets; but were used for forging in dies. Messrs. Avery of Birmingham were using them for that purpose very successfully. It was only after careful consideration and experiments with the hammer that they had adopted it in preference to the steam-hammers which they had used before for the same purpose. The hammers were also being used for planishing, for drawing down bars, and for forging scythes, and edge-tools such as spades and shovels. The American Tool Company at Antwerp had had one in use four or five years for the latter purpose; and since then another order had come from Belgium, which showed that the hammers were proving successful. Smaller hammers were very well suited for planishing copper and tin plate, small saucepans, frying pans, &c. Messrs. Shand Mason & Co. had been working one during the last six months, with which they made all their air-vessels, and the large domes for the boilers of their fire-engines. They found that the work done by the hammer was smoother than that done by hand, and much more regular. In fact they could get the surface polished like a mirror by means of the hammer, which they could not do by hand; and the work was also done much more quickly.

ON WOOL-COMBING BY MODERN MACHINERY.

BY MR. F. M. T. LANGE, OF ST. ACHEUL-LES-AMIENS.

The Combing of Wool by Machinery has made such vast progress towards perfection, that it will be unnecessary to do more than touch upon the old process of combing by hand; but a few words may be devoted to this subject, in order to give a clearer idea of the work to be performed on the raw wool.

The wool, after having been washed, is in a very tangled state, and full of little knots and burrs, technically called buttons, neps, or motes. It therefore requires to be straightened out, and to have the buttons, neps, or motes removed from it; and this can only be done by passing a comb through the mass many times.*

The wool works much more kindly if the combs (which have steel teeth) are warm, and if a little oil is put on the wool; hence in former days three hand-combers generally worked around one "fire pot," with burning charcoal in it, and each man placed one of his hand-combs on the edge of the pot to get warm whilst he was using the two others. Of these, one comb was placed on a projecting vertical spike attached to a post (the "pad post" as it was called), with its teeth standing upwards; and into this the comber lashed or struck the end of a bunch or body of wool which he held in his

* Saint Blaise, Bishop of Sebaste in Cappadocia, who lived in the second century, is supposed to have been the inventor of the hand-comb, and he died a martyr, his flesh being torn to pieces with his own iron combs. In the fourth century combing was effected with a single row of pins; when shorter wools came to be combed, the rows were increased up to five, or even more, in order better to clear the wool of knots and impurities.

hand, until the comb was loaded. He then took a warm comb, and repeatedly passed its teeth downwards, first through the end of the fringe or mass of wool in the fixed comb, and then gradually closer and closer up to the teeth; thus not only getting all the "buttons," which he had combed out of the wool, well into and behind the teeth of his own comb, but also combing out about half of the wool from the fixed comb into his own comb. He then placed the comb he had been working with on the post; and taking the third comb fresh and warm from the fire, proceeded exactly in the same way with this, until it became loaded in its turn. He then fixed this last comb on the post, and proceeded to draw off the projecting fringe of wool (or "milk it off," as it was sometimes called), drawing it off with his fingers and thumbs into a long and nearly clean sliver of wool. This clean wool is called "Top."

The above process cost about 2*s.* 6*d.* a lb. to do, and sometimes had to be repeated. In France it was common to take out any "buttons," remaining in the sliver after combing, with the lips, the sliver being held up against the light by the two hands in order to discover them. This process was called "Nactage."

The wool and impurities which remain in the comb after drawing off are called "Noil," and are sold to cloth-makers, who require a somewhat "fuzzy" thread for cloth, and not a long smooth fibre like that used for merino, mousseline-de-laine, serge, worsted, &c.

The first Wool-combing Machine was invented by the Reverend Edmund Cartwright of Doncaster in the year 1790, and he afterwards made further improvements in it. This is the same Edmund Cartwright who invented the surface condenser for steam engines, and the power loom, &c. His combing machine was described shortly in a paper by the late Mr. Benjamin Fothergill (Proceedings, 1853, p. 152). It was an exceedingly ingenious machine, considering that it was the first to deal with a material which until that time had only been treated by hand; and the motions that were adopted were evidently in imitation of the hand-motions in combing. Thus the "Crank Lasher" H, Fig. 1, Plate 30, has a pair of small feed rollers F, to deal out the sliver as the lasher H lashes it into the receiving comb C, which stands in the place of the fixed hand-comb. This is

a large circular comb travelling slowly round on a vertical axis, and having its teeth horizontal, and pointing inwards. The wool is worked or cleaned by a conical working comb W, which is carried round in a vertical circle, with the points of its teeth towards the points of the teeth of the circular receiving comb C. The "top" on the comb W is drawn off by the rollers R_1. The large comb C not only brings the wool round to be combed, but when combed carries it on to the other drawing-off rollers R_2, where it is drawn off in a clean sliver or "top," leaving the noil and dirt in the comb, from whence it has afterwards to be removed.

Mr. Cartwright made several improvements in his machine, but met with great opposition from the hand-combers. A Bill was presented to Parliament to suppress combing by machinery, but was thrown out by a large majority. The combing by this machine was not by any means perfect, nor indeed was the work done by hand perfect, but often had to be done twice over, causing great expense and loss in wool.

A little later Hawksley of Nottingham improved this machine, though still leaving much to be desired; his machine was made by Robert Ramsbotham, who it appeared did not think well of it. It was not until long after this that any combing machine worked at all on the true principle for obtaining really clean "top"; and it was still later that a machine was invented to take out all the "top," and thus leave none of it mixed with the noil.

The next combing machine that deserves notice, and in fact the first that was in any degree satisfactory, was not brought out for thirty years after Cartwright's. It was invented by Godart, of Amiens in France, in 1823, and was patented here in 1827 by John Platt. It was made by Collier, and was called "Collier's Comb." Some of these combs were at work as late as 1854, or perhaps a little later, in this country. The machine was of very simple construction. It consisted of two large circular and cylindrical combs W, Figs. 2 and 2A, Plate 31, (that is to say, combs in which the teeth stood up like a crown parallel with the axis), and two pairs of drawing-off rollers R_1 and R_2, and nothing more. The combs, which were heated by steam, were set with their peripheries running near each other, and their teeth

pointing towards each other, but with their axes somewhat inclined to the horizontal in opposite directions. Thus, when one comb had been loaded with wool, which was lashed into it by hand, the teeth of the other comb, as the two combs revolved, would enter the wool, and then, as the teeth separated, would comb it out, leaving the projecting fringe comparatively clean and free from buttons and neps. The combs were gradually advanced towards each other, so as to comb closer and closer up to each other. Finally the combs were stopped, and the drawing-off rollers R_1 and R_2 were advanced; the fringes of wool on each comb being entered between its drawing-off rollers, the rollers were started, and drew off a sliver of "top" P from the comb, the comb revolving very slowly until it had made one revolution. By this time all the "top" had been drawn off from it, and its teeth were then stripped of the remaining noil, and reloaded with wool to start afresh. With this machine the noil often amounted to 33 per cent. in weight of the cardings, *i.e.*, of the wool as brought to the comb, after it has been freed by washing and carding from dirt, tar, sand, stones, and rubbish. This comb was more suited for long wools, and one great objection was that the wool was imperfectly combed, and that the action was intermittent.

Many machines have been brought out since Collier's, but it is quite unnecessary to attempt to describe them all. The machines of chief note are tabulated below, in order of priority.

Heilmann's, 1845 (often called Schlumberger's on the Continent).
Lister & Donnisthorpe's, 1849–51–52.
Preller & Eastwood's, 1852 (known on the Continent as Opell's).
Noble's, 1853.
Crabtree's, 1854.
Lister's, 1856. (Improvement on Noble.)
Rawson's. (Improvement on Lister.)
Holden's, 1856.
Smith & Bradley's, 1871.
Mirfield & Scott's, 1870.
Little & Eastwood's, 1872 (made by Messrs. Platt, Oldham).
Lange's, 1881.

Heilmann's machine has been fully discussed in Mr. B. Fothergill's paper (Proc. 1853, p. 153). It may shortly be described as a working comb, to comb the front end of a sliver, with mechanical means for drawing off the portion combed to form a detached "tuft." The fibres of which the hinder part of this tuft was composed were then drawn through teeth, so that the whole was clean; and the combed tufts were pieced up by being laid one on the other. It is believed that this is the first case in which detached tufts of wool were drawn through teeth to comb them. This was essentially a short-wool machine, not adapted for long wool, but well adapted for combing cotton, which up to that time had only been carded.

Lister & Donnisthorpe's machine followed shortly after. This takes hold of the front dirty end of a sliver of wool lying in screw gills, by a positive nipping apparatus A (Fig. 3, Plate 30), composed of two jaws of metal, one covered with leather; these jaws draw out a portion from amongst the teeth of the screw gills by main force, and with such violence indeed as to break and strain some of the fibres. The tuft thus detached is then, by means of the carrying comb B, deposited, with the clean end outwards, on the teeth of a circular comb C, heated by steam, thus forming a fringe which is drawn off by drawing rollers. A dabbing brush D is used to press the wool down into the receiving comb C. All the noil in the circular comb is stripped out before it comes round again. This is a long-wool machine, though it can comb tolerably short wool also. It created quite a revolution in the trade, and was very successful.

Preller & Eastwood's (also known as the Opell on the Continent, from the name of the inventor) cleans the tuft of wool on cards, not combs, and then pieces the tufts up to form a sliver. The tufts are taken by a comb, fixed on the end of a reciprocating arm, from the end of a sliver (fed in by rollers intermittently), and the wool is carried past and over rollers clothed with cards, and deposited upon a receiving comb, worked by a travelling chain, from which comb it is drawn off by drawing rollers. A dabbing brush is used to press the carded wool down into the receiving comb. Any noil left on the receiving comb is stripped off subsequently.

Crabtree's machine differs from the last named, inasmuch as, in

place of a single reciprocating arm carrying a comb to take and deposit tufts, there are several arms having separate combs on them. The arms are capable of turning round on an axis, so that, although when they take wool from the slivers they are travelling point foremost, when they deposit the tuft they are travelling head foremost. The cleaning is by carding rollers, very much as in the last machine, and the noil is similarly stripped from the receiving comb.

Noble's machine is very peculiar; it consists of a large circular comb some four or five feet in diameter, with a smaller comb, about one fifth the above in diameter, placed inside it and running close to it at one point. The two circumferences travel at the same speed, and both are heated by steam. The machine is fed with a complete circular fringe of slivers, which are arranged outside and around the large comb, and are drawn from a number of "balls" or reels of slivers, about eighteen in number. The ends of these slivers are passed through open-ended boxes or troughs, hinged at their outer ends; so that, on being lifted or depressed, they lift the ends of the slivers, or deposit them in the large comb respectively; but inasmuch as they only so deposit the slivers at the very point where the large and the small circular combs come together, they engage the ends of the slivers in both combs at once. As these combs in their revolutions separate, the wool is separated, and the fringe projecting from each is combed by the other, thus presenting two clean fringes of wool, both of which are drawn off as "top," each by its own drawing-off rollers. A quick-acting dabbing brush is used to press the wool down into the two combs at the proper point. The noil is stripped off from the small comb before it comes round again, and the ends of the slivers are lifted out of the large comb and advanced a little, ready to be again deposited at the right point into the two combs. This machine is well adapted for short wool.

Lister's improvement on Noble consisted in applying two small circular combs instead of one, inside the large comb, which was made larger for the purpose, thus producing a double machine.

Rawson's improvement on Lister consisted in an improved mode of feeding the circular receiving comb, by doing away with the

nipping apparatus, which often injured the wool, and by causing the feeding head, carrying a set of pins, to advance right up to the receiving comb, and place the projecting end of the sliver into it; so that, on the feeding head retiring, it combed the fringe projecting from the receiving comb, and the receiving comb combed the end of the sliver projecting from the feeding head. The outside fringe on the receiving comb is drawn off by drawing-off rollers as "top," and the short fringe projecting inside the receiving comb is drawn off by other rollers, and returned to the feeding head to pass through again to be combed.

Holden's machine has two pairs of feeding rollers; but (instead of having a reciprocating arm, like Opell's and Crabtree's, or a drum with a series of combs to take the fringe, and then having the projecting tuft combed by card rollers), the feeding-on rollers, called "Boxers," themselves lash the wool into the receiving comb. After this it is held by a pressing plate, and the projecting fringe is combed by a set of gill fallers working from the bottom upwards. This apparatus is called the "Square Motion." The fallers have some eighteen rows of pins each, and are seven in number; the wool taken by the square motion is called "Robbins," and is returned to the cards. The carrying comb has two rows of pins and is 4 ft. in diameter. A comb called a "Nacteur," larger by two or three rows of pins, and sometimes made in segments, comes down into the tuft or combed fringe, to prevent impurities passing through at the drawing-off, which is effected by horizontal rollers. The "noil" is afterwards taken out from the receiving comb by means of a small scraper moved rapidly up and down.

Smith & Bradley's, and Mirfield & Scott's improvements on Noble simply provide a very narrow clean layer in the slivers, as they come round, to be deposited in the minute space between the two circular combs. This small clean space is obtained by depositing the slivers in the large comb, before they come round to the point of coincidence, then withdrawing them a little way so as to give the beginning of a combing, and then lifting them again and advancing them, so as to deposit this combed and clean part just at the point of coincidence

of the two combs. This is with the view of preventing any small button or nep escaping into the "top."

Little & Eastwood's machine consists of a wheel or frame, with some six or more sets of nipping apparatus on it. These take tufts from a screw-gill feeding-head, and deposit them in a circular receiving comb after the general manner of Lister's machine; the sliver is afterwards drawn from the receiving comb by drawing-off rollers in the usual way.

Lange's machine introduces an entirely new process, and for the first time combs the whole of the "top" out of the wool before letting it go. This it accomplishes by first combing out the bulk of the "top," and then combing out such portions of "top" as are still left mixed with the wool. It thus obtains a much larger proportion of "top," and leaves nothing but absolute noil to be stripped out of the comb, and go away as noil; instead of having so much "top" mixed with the noil, as to necessitate recarding before the whole can be finally combed. It is another advantage of this machine, and a most important one, that it leaves the wool the full length after combing, because the wool is invariably placed on two combs, which comb it by separating; so that it is neither held down by pressing-plates, nor drawn off with anything like a nip, holding the wool fast.

A general perspective view of the whole machine is shown in Plate 35; and in order to make this process of combing quite intelligible, the important parts are shown in Figs. 4, 5, and 6, Plate 32, while *each* operation or motion is also shown by a separate section.

The Sections, Nos. 7 to 13, Plates 33 and 34, show the process of combing to which the wool is subjected in its passage from the head comb H, Fig. 4, Plate 32, to the circular receiving comb C, and the subsequent drawing off of the "top" from the latter comb; while the Sections, Nos. 14 to 20, Plate 34, show how the wool, left from the former process in the receiving comb C, is combed by the large and small circular combs C and *c*, and how the "top" is subsequently drawn off.

In Fig. 4, C is the large circular receiving comb, very like that

used in a Lister or Rawson machine, but having more teeth in it as a rule, and at a finer pitch. H is called the head comb, F the feeding comb, and B_1 B_2 the dabbing brushes, Plate 33.

In Section 7, the head comb H has retired from its previous stroke, the dabbing brush B_1 has risen, and the feeding comb F has gone back, ready to receive the sliver when lifted up into it by the grill bars L, between which the sliver enters.

In Section 8, the grill bars L have been raised, have lifted the sliver out of the teeth of the head comb H, and pressed it up into the teeth of the feeding comb F.

In Section 9, the head comb H has advanced close up to the circular receiving comb C, and at the same time the feeding comb F has moved forward through a greater distance, and drawn forward the sliver with it, through the grill bars L, so that the clean end projects well over and beyond the teeth of the comb C.

In Section 10, the grill bars L have been dropped, and the dabbing brushes B_1 B_2 have both descended, and pressed the sliver into the teeth of the circular comb C and the head comb H.

In Section 11, the head comb H has been drawn away from the circular comb C, and has consequently combed the fringe of wool remaining in the circular comb C, whilst the end of its own sliver has been combed by the comb C. Thus both portions are combed by the separation of combs, which is the best possible method.

The brush now rises again into the position shown in Section 7, the feeding comb F goes back to receive a further portion of sliver, and the operation is repeated as before.

It is obvious that it is a clean fringe of wool which is left on the inside of the comb C, as well as on the outside, because this inside fringe is that which was combed by the circular comb in the former stroke. These two fringes have now to be drawn off.

Section 12, Plate 34, shows how, as the circular comb slowly revolves, it brings the outside fringe to the horizontal drawing-off rollers R_1, shown also in Fig. 4, and placed outside the comb, by which a clean sliver of combed wool is drawn from the comb. Further on, as in Section 13, the comb brings the inside fringe to the vertical drawing-off rollers R_2, by which another clean sliver of combed wool (called

"Backings") is drawn from the comb C, and run out of the machine, together with the first sliver, through a tweedler I.

In Sections 14 to 20, Plate 34, C is a section of the large circular receiving comb as before, and *c* a section of the small inner circular comb.

In Section 14, C is shown with the wool that was left in it after the previous drawing off of "top" from the inside and outside; and *c*, the small circular comb, is still at a distance from it.

In Section 15, this wool has been lifted out of the comb C, in an unbroken state, by lifting knives K, Figs. 5 and 6; and the small circular comb *c* has approached close up to the large comb C.

In Section 16, this wool has been shunted sideways, about half its width, by passing through an oblique trough T, Figs. 5 and 6; and is ready to be forced down into the two circular combs C and *c* by the quick-acting dabbing brush B_3.

Section 17 shows it so pressed down by the brush B_3, so as to be thoroughly held by the two combs, about half being in each comb. Thus the centre of the mass of wool left in the large circular comb C, after the first operation, is now at the exact line of junction of the two combs C, *c*, Fig. 5.

In Section 18, the brush B_3 has risen, and the combs in their further revolution have separated from each other. Each has combed the wool projecting as a fringe from the other, thus leaving one clean fringe of combed wool on the inside of the large circular comb C, and another on the outside of the small circular comb *c*, the wool thus being combed by the separation of combs as before. Of these fringes, that which projects inside the large comb is allowed to remain in it, and to pass round to the feeding-head, where the fresh wool is being fed in. It then passes on, as part of the main bulk of wool inside the large comb, and is drawn off by the vertical drawing-off rollers R_2, Section 19. The other clean fringe of long wool, which is left in the small receiving comb *c*, is drawn off by a third pair of drawing-off rollers R_3, Section 20, and forms an additional or third sliver of clean wool, which is added to the other two, and runs out of the machine through the tweedler J, so as to form one continuous body of clean "top."

The noil remaining in the small circular comb is lifted out by lifting-knives at k, Fig. 4. This is all actual noil, and is used at once for the ordinary purposes for which noil is adapted; it is rather more valuable than the noil ordinarily obtained, as it has had less strain put on it, and is less broken than if it had been subjected to a positive nip in a nipping apparatus.

The clean "top" is also more valuable than usual, because it has not been broken or strained in the combing by any nipping apparatus, nor has been violently treated in any way; thus it remains of its full natural length, or about one-fifth longer than if it had been combed on a machine working with a nip, and therefore can be spun to a higher number or "count."

The proportion of noil to cardings is greatly reduced in this machine, and is in fact brought down to a minimum. Another very important item is that the machine takes such a heavy feed, and works so fast, that it does much more work in a day than most machines; besides which, no part of the wool requires carding over again.

Abstract of Discussion on Wool-Combing Machinery.

Mr. E. A. COWPER showed the way in which the operation of combing by hand was carried out. The woolcomber rolled up the wool into a sort of tuft, without twisting it, and then loaded the post comb with the end of the tuft. In this tuft some of the wool was clean and some dirty, and all mixed. In working it with the

hand-comb, care had to be taken to begin at the extreme end of the fibres; if the combing were begun too close up to the teeth of the post comb, the wool would be torn all to pieces. After having at length combed the tuft close up to the teeth of the post comb, the man then proceeded to draw the combed wool off from the post comb. It was so firmly held in the comb that it was necessary to have a pair of pincers to lay hold of it. With these it was gradually drawn down, commencing as before on the part furthest from the teeth; there was rather a knack in catching hold of it in the right place, not too far from the teeth and not too near. If it were caught hold of too far off from the teeth, it would be pulled all to pieces; if too close to the teeth, the pull would tear it, or break it, or it would not come out of the comb. The comber kept on pulling it —"milking" it off, as it was called—until he had got a sliver of tolerably clean wool about two yards in length. If the comber drew it too much at a time, the sliver was broken; it was therefore necessary to draw a little only each time, a fresh hold being taken with the pincers before the next drawing.

Mr. Lange exhibited a few samples of combed wool, which he had brought over from Amiens to show what quality of work his machine produced. One sample was a sliver of "top" as it came direct from this combing machine. On reference to the drawings it would be seen that the comb was always kept completely filled with wool, which was continually drawn off and fed on; there was in fact only a small portion of the machine which was not completely filled with wool. He was able now to exhibit a sample of Australian Botany wool obtained during one minute's trial, when the machine was producing 500 lbs. of top in a day of twelve hours. There were also samples of French wools with two kinds of noils, one off the old machine and the other off the new machine, from which it was clearly visible that that off the latter was less than half the size of that off the former. The accompanying Table showed the comparative percentages of noil made from the cardings, when combing various lots of wool in one of the former machines at his works, and in his improved machine.

Comparison of Wool Combing by Old machine and by Lange machine.

No. of Lot.	Description of Wool.*	OLD Machine.		LANGE Machine.	
		Percentage of Noil to Cardings.	Weight of Top per day of 12 hours.	Percentage of Noil to Cardings.	Weight of Top per day of 12 hours.
No.		Per cent.	Lbs.	Per cent.	Lbs.
5924	Buenos Ayres, very short fine skin-wool, washed	41·0	225	20·0	300
5954	1st quality French wool, in the grease . . .	32·0	314	16·0	419
5955	3rd " " " " " . . .	24·0	392	12·7	522
5966	1st " " " washed	30·0	294	14·5	392
5974	2nd " " " in the grease . . .	22·0	337	10·8	450
5970	2nd " " " " " (Champagne)	22·5	300	11·0	400
5977	2nd quality French skin-wool	17·5	255	8·5	340
5978	1st " " "	21·0	250	10·3	334
5979	1st " " "	19·0	324	9·6	432
5997	1st quality Australian Botany wool	27·5	400	13·3	500
6012	1st " French skin-wool, dry	15·0	330	7·0	440
6013	2nd " " " "	12·0	450	5·8	600

* The "washed wool" is what is sheared from the living animal after washing. The "skin-wool" is what is obtained from the skins of dead animals, from which it is removed with the aid of caustic lime. Of each kind there are generally four qualities, the first being the finest and therefore the most valuable. Different lots vary so much in regard to the cleanness of the cardings delivered to the combing machines, as to preclude a fair comparison of the two machines, except where both of them comb from the same lot.

It would be seen that with the fourth lot the proportion of noil to cardings in combing "first-quality French wool washed" was 30 per cent. with the old machine, while with the new machine it was brought down to only 14½ per cent., or less than half; at the same time the weight of "top" produced per day of twelve hours was increased from 294 lbs. in the old comb to 392 lbs. in the new. Similar results were shown with the other lots in the Table; and they had been arrived at by being able to have in the new machine very much larger or closer combs, of which he had brought samples, in order that they might be compared with the old hand-comb that Mr. Cowper had kindly shown. In the hand-comb the pins were about six to the inch, whereas in the present comb, of the most modern make, they were forty to the inch. They were made slightly oval, in order to keep them strong enough when made so

small as required for the closer pitch. One of the samples exhibited of combed wool corresponded with the extraordinarily high production of 640 lbs. of "top" in a day of twelve hours, and in that case also the noil had been very much reduced; thus attaining the great aim in all wool-combing machines, namely to give as much "top" as possible and as little noil as possible, without deteriorating the value either of the "top" or of the noil. In all combing operations it ought to be remembered that wool was a tender fibre, and every care should be taken not to strain it in any way, but to leave it of its full strength and elasticity or "nerf," as this was of the greatest importance in "top" for spinning to a high number of yarn. It might be remarked that the fibre of wool, when examined in the microscope, appeared full of little joints from end to end; and if these were strained, the fibre lost its elasticity to a great degree.

The PRESIDENT drew attention to the new combs exhibited, which were beautiful specimens of work. He enquired what was the full size of the circle of the comb in the machine.

Mr. LANGE replied that the circle of the receiving comb was 3 ft. diameter. The round pins in the combs as formerly made were not so strong; and it was by a great improvement in machinery that they were now able to be made oval.

Mr. A. GREENWOOD said that several of Mr. Lange's combs had been at work for upwards of six months, and there were now eight machines at work in his wool-combing factory at Amiens, while two more were being altered to the new plan. He (Mr. Greenwood) had visited Amiens on two occasions on purpose to examine these machines thoroughly, and he was convinced they were a great improvement on previous machines. His own firm had undertaken the manufacture of the combs in this country, and he hoped that, by the time of the meeting of the Members of the Institution in Leeds in the summer, they would be able to show some of the combs at work there. One of the machines was going to be exhibited at the Exhibition at Bradford, which would accompany the opening of the Textile College, early in

June, by the Prince of Wales. As Mr. Lange had said, the great advantage of the machine was the enormous amount of work that it would turn out, together with the reduction of noil. He believed it was generally admitted that it would turn out about double the quantity of the same class of wool, as compared with the machines generally used in Bradford, such as Noble's or Holden's; those machines being principally used for combing Botany wool in Bradford.

Mr. Lange, Sen., said that for twenty years he had worked in France with the earlier machines that had been described in his son's paper, and his success was owing to a single point: he could not say that he had been able to beat all the other machines in every respect, but he had succeeded in doing one thing which the others did not, namely in leaving the combed fibre longer than the other machines did. At the same time however he had made more short wool or noil, which the French "top" merchants were not pleased at, and they told him that he must find some means of reducing that proportion. For some time he had not listened to them, because it was difficult to please everybody; but at length the means had now been found, not only of reducing the proportion of noil, but also of increasing the produce from the machine and making better work. The practical difficulty lay in the circumstance that to reduce the noil it was necessary to reduce the width of the comb, whilst on the other hand it was really on the width of the comb that the produce of combed wool from any machine depended. This difficulty had been surmounted by increasing the number of rows of teeth in the combs. If a comb had only one row of teeth, it clearly could not comb the wool as clean as with two rows. To reduce the noil to the proportion desired, he had been obliged to fix the number of rows at seven; but even that did not do justice to the wool, and they had accordingly advanced to the ten rows they were now using, which came up to his *beau ideal* of what a combing machine should be. The ten-row new machines were reducing the noil by one-half, and doing better work than had formerly been done with seven rows. To sum up, the work was better, the wool was longer, and the

produce was nearly double of that from any other machine he knew of.

Mr. E. A. Cowper said he had seen the machine at work and had examined it carefully, and he had certainly learned something from it in wool-combing. Some years ago he had a great deal to do with some of the disputes about wool-combing machines—Heilmann's, Lister's, Crabtree's, and others; and Mr. Lange's machine was certainly a very great improvement upon what was then done. In those days, the object was to get the wool cleaned somehow, without caring so much about noil; but with the present machine, which combed what would otherwise go away as noil, all the long wool was got out, and nothing sent away but real noil. The present machines were thus working in the most economical manner possible, because they were getting as much valuable wool out of the mass as possible. There was very little real noil in some wools. Although, when the locks of wool were taken up, the wool looked very dirty, yet by a very few strokes of the comb, properly applied, it became reasonably clean; and what was left behind, if the action were repeated twenty times, would be very small. The expense of combing wool by hand was very great, namely about 2*s.* 6*d.* per lb. if it was done properly; partly because it had to be done twice. Lister's machine cut the cost down to 5½*d.*, and now the price was about 2½*d.* to 4*d.* His own opinion was that Mr. Lange would have a very great run with his machines. Messrs. Greenwood and Batley were now taking up the matter *con amore*, as far as England was concerned, making the tools for it, and everything else required. At the Leeds meeting the Members would have a treat in seeing the machine at work. It would not only be at the Bradford Exhibition, but he hoped at other places also.

There was one point that might be mentioned, which was not obvious at first sight, namely that the wool, with this machine, was not strained, or pulled with violence, or broken; for just as a man's arm, if strained and pulled partly out of joint, would never be right again, or have the same spring in it, so if the wool was nipped and pulled violently, the spring was taken out, and it was not as good as

it was before. In this machine the wool was entirely combed by the separation of combs, and there was no "nipping" or "pressing plate" used. He had no doubt that, in actual practice, the machine would be a great favourite. Mr. Lange, Sen., had informed them that it had reduced the noil to rather less than one-half of what it had been before, and did an enormously increased quantity of work; and that of course was a very great improvement. Moreover this machine, unlike most others, could be adjusted quickly to comb different classes of wool. If they could comb the wool in England as well as this machine did it, and pay attention to obtaining the soft and fine qualities, as was done in France, he hoped that what was called "French merino" and "mousseline-de-laine" would be made in England equal to the French, which, he was sorry to say, was not the case at the present time.

The President was sure they were much indebted to Mr. Lange for having brought his valuable improvement before them, and for having taken so much trouble in bringing over the specimens he had exhibited. It would certainly be something to look forward to, in connection with the summer meeting in Leeds—which he believed would be one of the most successful meetings they had ever had—to see there so beautiful a specimen of mechanism as this in actual operation.

ON MACHINERY FOR THE SOWING OF SEED.

By Mr. J. J. SMYTH, of Peasenhall.

In Mr. W. R. Bousfield's paper read before the Institution (Proceedings, October 1880, p. 259) the operations of agriculture were classified under four chief divisions. It is with the second division that the writer will endeavour to deal, viz., the Sowing of seed.

In order that a fair idea may be formed as to the advance which has been made, as well as to furnish material for future discussion, it is proposed to glance not only at the practice in our own country, but also at that on the Continent of Europe and in America.

In England drill-culture has become so universal that, were it not for including foreign countries in this survey, it would scarcely be necessary to treat the subject of sowing seed in its two-fold form, viz., sowing broadcast and drilling in rows; but broadcast sowing being still practised in some countries, it is the purpose of this paper to give an account of the most approved broadcast sowers as well as drills.

The subject may be divided into three heads:—

1. The delivery of the seed to the sower.
2. The regulation of the quantity to be sown.
3. The bringing of the seed to the soil.

1.—Delivery of the Seed to the Sower.

A machine should sow uniformly the same quantity of seed, whether travelling on level ground, along the side of a hill, or up and down hill. It should also adapt itself easily and quickly, not

only to all kinds of grain and small seeds, but to all conditions of the same grain, without being liable to clogging.

A great variety of contrivances have from time to time been devised with this object, but it would be beyond the province of this paper to do more than select those most practically useful.

For convenience the writer divides them into three classes :—

a. Aperture delivery.

b. Force-feed delivery.

c. Cup delivery.

Class (a). Aperture delivery.—Of all the systems this is the most rudimentary, and it is proposed to give one example only, that of Mr. Ben Reid of Aberdeen. His apparatus is styled by him the "Disc" Broadcast Sowing machine.

Fig. 1, Plate 36, shows a section of the seed-chamber of this machine. The bottom of the chamber has perforations at intervals, through which the seed may flow; and attached to the underside of the same is a sliding plate furnished with perforations to match, and capable of longitudinal adjustment. The size of the apertures can thus be varied to suit the quantity of seed to be sown. In order that the seed may be kept flowing regularly, a shaft A, carrying a series of differential discs B, is placed above each aperture and made to revolve.

Class (b). Force-feed delivery.—This class of delivery has been universally adopted in the United States, and has found some warm advocates in this country. Before proceeding to consider the various American arrangements, it is proposed to introduce the oldest example of force-feed delivery, known in this country as the Brush system. This arrangement is only used for small seeds, such as clover, turnip &c., and usually as a hand-barrow machine; for which purpose its lightness is its greatest recommendation. Fig. 2, Plate 36, gives a section of the seed chamber and cylindrical brush. The brushes are imbedded in the seed, and in revolving are made to rub against perforated plates or discs, and thus to force the seed through the perforations. These discs, shown in detail, Fig. 3,

are arranged in pairs with varying sets of perforations in the outer plate, and one large opening through the inner plate; and they are connected to one another by a rivet through their centres. At A is a section of the brush, B shows the inner plate, and C the outer plate or disc: by partially rotating the outer plate over the inner, one or other set of the perforations in the outer plate is opened, and thereby the quantity of seed sown is regulated.

As regards the American force-feed arrangements there is a considerable variety.

Fig. 4, Plate 36, is a transverse section, and Fig. 5 a back view, of the McSherry seed box, which may be accepted as fairly representative of the construction of the American machines generally: even the feed arrangement of several makers is very much the same, except in the grooving of the feed rollers.

Fig. 6 is an enlarged section of the actual feed in the McSherry arrangement.

Fig. 7 is a perspective drawing of the McSherry feed roller by itself.

Fig. 8 gives a back view of the "Farmer's Friend" roller.

Fig. 9, Plate 37, is a back view of the "Triumph" roller.

Fig. 10 is a section, and Fig. 11 a side view of the "Superior" force-feed disc.

On reference to the transverse section of the McSherry apparatus, Figs. 4 and 6, Plate 36, it will be seen that the seed passes through openings in the bottom of the seed chamber A to the feed roller B, which forces it through the opening C in the rear.

One difficulty which the American inventors have had to contend with has been the tendency to intermittent discharge, and consequent gaps in the seeding. In order to obviate this evil, recourse has been had to a variety of contrivances, with more or less success; the greatest difficulty existing when a small quantity is being delivered, or the seeding is thin. Thus the McSherry feed roller is grooved spirally, Fig. 7; whereas the roller in the "Farmer's Friend" is a cylinder with zigzag ribs, Fig. 8.

These arrangements appear to have a tendency to crowd seed and dust to one end of the chamber, with the risk of forcing it in between

the end of the feed roller and the chamber casing; to obviate this a washer or shield E, Figs. 6 and 7, is fitted at the end of the McSherry roller, and revolves with the roller. In the "Triumph" feed-roller, Fig. 9, the speed is always the same, and the effective delivering surface is increased or diminished by means of the sliding sleeve A.

In the foregoing examples the feed-rollers have their breadth about equal to their diameter; but other varieties exist which assume the form of a flanged disc. These arrangements however do not appear to give satisfactory results, and the writer therefore merely introduces one example, namely the "Superior" disc, Figs. 10 and 11, Plate 37.

Class (*c*). *Cup delivery.*—This kind of delivery has found almost universal adoption, not only in England, but also throughout Europe. It comprises two systems: in the one the cups are indentations on the periphery of a revolving disc, Figs. 12 and 13, Plate 37, whereas in the other system the cups are fixed into the sides of a revolving disc, Figs. 15 and 16, Plate 38. The former may be termed the Indented-disc, and the latter the Side-cup system.

The indented-disc system was in use in England in the early part of the present century, but the side-cup has now become all but universal in this country. The indented-disc has however obtained extensive use in Eastern Germany. Mr. Rudolf Sack of Plagwitz-Leipsic has adopted that arrangement as a specialty, and is manufacturing drills on this principle in considerable quantities. Fig. 12, Plate 37, gives a transverse section of the seed-box in one of these drills: in this A is the seed-chamber or reservoir, from which the seed passes through the opening B to the indented disc C, and the disc in revolving delivers the same into the hopper D.

Fig. 13 shows an elevation of Mr. Sack's indented disc. Formerly Mr. Sack made use of a separate disc for each row to be sown, but the drawing shows a double disc, which has been adopted by him in drills where the rows are very close together, and consequently difficult to arrange with single discs.

The side-cup system, almost universally used in England, and very generally throughout Europe, is illustrated by Figs. 15 and 16,

Plate 38, in which A is the seed chamber, and B the opening through which the seed passes to the delivery cups C: by these it is delivered into the conducting hoppers D.

Each hopper is fitted with a door at O, which, when pulled back into the position shown by the dotted lines, closes the hopper, and allows the seed to fall back again into the lower chamber E.

The flow of seed from the upper chamber A to the cups C is regulated by means of slides governing the openings B; thus for small smooth seeds the openings B are very much contracted, whereas for large, rough, or light seeds they are enlarged. Usually these slides are of a rectangular shape, and they are raised vertically by most of the leading makers; as a rule, all the slides are raised simultaneously, thus ensuring uniformity in the size of the various openings. The writer some years since introduced a segmental arrangement into the drills manufactured by his firm, which is shown in Fig. 15, Plate 38. H is one of a series of segmental slides connected together at their upper ends by the transverse sliding bar K, to which each is fixed by the thumb-screw J. The bar K is furnished with a connecting-rod N, the outer end of which carries a screwed swivel-nut Q, working on the crank-screw L. The bar K and the slides H are moved and adjusted by turning the crank-screw.

The hoppers D sit in the sockets F, and are held in position by means of the hasps G. It will be seen that when the cup discs C and the shaft S upon which they are mounted require to be removed, the hoppers D must be taken out of their seats; and unless they are replaced and properly hasped down, before the machine is put in action, they are liable to rise and come into collision with the cups, thus causing injury both to the cups and hoppers.

In order to remedy the inconvenience of removing the hoppers, and the consequent risk of injury, the writer devised an arrangement which he exhibited at Paris in 1878, and which is illustrated in Figs. 17 and 18, Plate 39. Fig. 17 shows a longitudinal section of the seed box, taken along the line *ab*, Fig. 18, with the cup-wheels and receiving hoppers; and Fig. 18 is a transverse section taken through the line *cd*, Fig. 17. Whenever it is desired to take out the cup-wheels and spindle, the plate L, Fig. 17, is turned down; and

being connected to the shoot K by a connecting link, it pulls back the shoot out of the track of the cup-wheel into the position shown by the dotted lines. Thus the one action serves both to lay down the plate L, so as to give egress to the spindle F, and also to tilt back the shoot K, giving free exit to the cup-wheel.

The same tilting arrangement is made use of when it is desired to stop any of the hoppers from feeding, the seed then falling back again into the seed chamber.

In order further to facilitate the removal of the cup-wheel spindle, the writer adopted the drop bearing shown in Figs. 19 and 20, Plate 40. The spindle bearing is in a plate N, which is pivoted upon a fixed stud P, and is held in working position by the catch or pawl Q. Upon releasing the catch, the plate N is free to fall, and thus give egress to the cup-wheel spindle M.

2.—Regulation of the Quantity of Seed to be sown.

This object is attained in two ways; either by varying the discharging capacity, or by changing the speed of the delivering apparatus. Thus in the aperture systems the size of the discharge openings is increased or diminished; in some other cases, as for instance in the force-feed arrangement, Fig. 9, Plate 37, the effective feeding surface is varied; whereas in other cases the speed at which the delivering apparatus revolves is varied by means of change wheels.

This variation in speed by the use of change wheels is generally admitted to be the most satisfactory and reliable; for which reason the writer has thought it best to deal rather more fully with the various appliances for that purpose.

In the various arrangements illustrated in Figs. 21 to 24, Plates 41 and 42, it will be seen that motion is communicated from a cog-wheel on the nave of the travelling wheel direct to a cog-wheel on the delivering apparatus; whereas in Figs. 25 to 27, Plates 43 and 44, a train of wheels are made use of. In the former case, it follows that, when larger or smaller change wheels are applied, the seed box must be raised or lowered in order that they may gear correctly; whilst in the latter cases the seed box is supported at one definite fixed point. The direct gearing is simpler; but, on the

other hand, the arrangement by means of a train of wheels enables the coulters, levers, and conductors to be arranged in the most effective manner, and also admits of quicker and more convenient adjustment of the change wheels.

Fig. 24, Plate 42, represents a screw-lifting arrangement, in which the hook D, supporting the seed box A, is fitted with a nut to receive the vertical screw B, and is furnished with a pointer C to indicate upon an index-plate the correct height corresponding to the size of the cog-wheel J on the cup-wheel spindle; thus ensuring that the cog-wheel J shall gear a proper depth into the cog-wheel H on the nave of the travelling wheel E.

The cog-wheel H sometimes consists of two wheels, side by side, of different diameters; in which case the index-plate has two sets of figures, that to the left being used when gearing into the smaller wheel, and that to the right when gearing into the larger one. This arrangement practically allows two sets of speeds to be given with one set of change wheels.

In Fig. 22, Plate 41, the seed box A is supported by the lever B, by means of which the seed box is raised or lowered, so as to bring the cog-wheel J, which may be of any size, into proper gearing with the cog-wheel H on the nave of the travelling wheel. The lever B is furnished with a crank-handled set-screw C, the end of which is reduced so as to enter into any one of a series of holes drilled into the rim of the quadrant bracket D. These holes are so spaced that the figures on the bracket D, corresponding to the sizes of the cog-wheels to be applied to the cup-wheel spindle, may be read through the slot in the lever B.

Fig. 23, Plate 42, shows an arrangement in which the seed box A rests upon numbered iron blocks, one of which is shown, marked 22. A special pair of blocks are furnished for each size of cog-wheel which has to be applied to the cup-wheel spindle. When changing cog-wheels, the seed box is lifted so as to rest on the hook E, the numbered block is taken out of the vertical groove in which it fits, and is replaced by a block corresponding in number to that of the cog-wheel J to be affixed, and then the seed box is again lowered into working position. It will be observed that the cog-wheel J on the cup-wheel spindle takes its motion direct from the cog-wheel H on the nave of the

travelling wheel. This arrangement, in connection with an iron side-plate X, replacing the wooden cill previously in general use (which was a continuation backward of the wood cill B), was brought out by the writer's father in the year 1843, and led to the general use of iron side-plates instead of wood.

Figs. 19 and 20, Plate 40, explain an arrangement brought out by the writer in 1878. In this the first motion is communicated at the right-hand end of the drill, Fig. 20, from the driving wheel H on the nave of the travelling wheel to the cog-wheel B fixed on the counter-shaft C. This shaft extends underneath the seed box A to the left-hand side of the drill, Fig. 19, and there carries the driving-wheel D; thus, through the intermediate wheel E, communicating motion to the wheel J on the cup-wheel spindle M. When it is required to change the cog-wheel J for one of a larger or smaller size, the radiating plate G, held in position by the bolt I, is moved to the left or to the right, carrying with it the stud and intermediate loose wheel E.

The position for the radiating plate G is indicated by figures on the index-plate L, these figures being read through a slot in the radiating plate, and corresponding to the various change wheels which may be attached to the cup-wheel spindle M.

In order that a greater range of speed may be obtained, the driver D may be exchanged for a larger one; and in that case the bolt I is moved into the upper slot of the index-plate L, thus bringing the upper row of figures into use as indicators.

Fig. 25, Plate 43, represents an arrangement brought out by Mr. Samuel Kell, of Ross, in 1874. H is the driving cog-wheel on the nave of the travelling wheel; B and C are intermediate wheels, mounted upon studs attached to the link-lever F, and communicating motion to the wheel J on the cup-wheel spindle. The stud on which the wheel C revolves is capable of a sliding adjustment in a slot in the lever F, whenever the cog-wheel J has to be exchanged for one of a different size. The link-lever F hangs upon a gudgeon, through which the cup-wheel spindle passes, and thus radiates from the same centre; by raising this lever the wheels are taken out of gear when the machine is travelling on the road.

Somewhat similar is the American arrangement, Fig. 26, Plate 43, where the driving-wheel H gears into an intermediate wheel C, and

this latter, through a pinion, drives the wheel J on the cup-wheel spindle. The wheel C is carried by a bracket, which is movable round the axis of the travelling wheel; and is also adjustable radially by means of a slot in this bracket.

3.—Bringing of the Seed to the Soil.

This last division of the subject of this paper leads to the consideration of the two systems, namely Broadcast Sowing and Drilling.

The Broadcast Sowing Machine.—This comprises a seed-box mounted on two travelling wheels, and furnished with shafts or pole for traction by horses or oxen. In most cases a slanting board is suspended from the under-side of the seed-box, for protection of the seed from wind, and to secure a better distribution. Motion is communicated to the delivery apparatus by means of cog-wheels in connection with one of the travelling wheels.

Figs. 21 and 22, Plate 41, represent Kaemmerer's Broadcast Sower, as constructed by the writer's firm, in which it will be observed that the seed-box A is furnished with side-cup delivery, as shown in Plate 38, and with cog-wheel gearing as represented by Fig. 22. The main feature however is the distributing board, Fig. 21, furnished with a series of dividing blocks and pegs, which ensure a perfect distribution of the seed.

Corn and Seed Drills.—In preparing this paper the writer was anxious to introduce the most improved existing examples: he however deems it not out of place to exhibit before the members a working model of the Suffolk Drill constructed by his father in the year 1838; which will at least serve for comparison, and thus make apparent the advance which has since been attained. Fig. 23, Plate 42, represents the present type of Suffolk Corn Drill; and Figs. 27 to 29, Plates 44 to 46, the writer's latest "Nonpareil" design.

On reference to Fig. 27, Plate 44, it will be seen that a drill is composed of—

1. A seed-box with its seeding apparatus;

2. A frame mounted on two high travelling wheels, the latter furnished with cog gearing for driving the seeding apparatus;

3. Levers with the accompanying coulters, by means of which the seed is deposited in the soil;

4. Conductors, which convey the seed from the seeding apparatus to the coulters;

5. Apparatus for guiding or steering the drill.

1. The seed-box in its various arrangements has already been fully described.

2. The frame, Figs. 27 and 29, Plates 44 and 46, whilst serving as a support to the seed-box A, is connected, by a fore-carriage attachment or otherwise, to the shafts, by means of which the horses are attached; it is also continued backward, and there carries a roller R, for lifting the coulter-levers D and D_1 out of the ground. The same roller serves also another purpose, that of exerting a downward pressure upon the levers D, when the weights G by themselves are insufficient. Its mode of action is as follows.

The press-levers J are connected at their front ends to the lever beam E, and near their middle to the transverse bar K; whilst at their rear ends they carry vertical standards L, terminating above in hooks M, to which chains N, coiled round the roller R, are attached. Thus, by turning the roller in the reverse direction to that for raising the coulter-levers, the chains are made to exert a pressure, through the standards L, levers J, and cross-bar K, upon the coulter-levers D and D_1.

By continuing to turn the roller R in the same direction, it is possible to raise the travelling wheels clear of the ground, thus furnishing a convenient method for supporting the machine when the wheels are taken off for greasing.

In some machines the vertical standards L are dispensed with, and instead the press-levers J are extended back beyond the coulter-levers D, sufficiently far to admit of a heavy weight being attached to each; but in this case it follows that the convenience for greasing the travelling wheels is sacrificed.

It will be observed in Fig. 23, Plate 42, that the arrangement for turning the roller consists of four handles in the form of a cross; this is a plan still largely in use, but other means have of late years been introduced. Thus in Fig. 27, Plate 44, is shown an arrangement brought out by the writer in 1864. Here O is a worm wheel fixed upon the roller R, and driven through the worm Q, by means of the crank-handle C. The worm spindle is furnished with a catch wheel S, and is held in any desired position by the drop-catch T, Fig. 28; which latter is free to turn back when the crank-handle is put in motion.

3. The coulter-levers are a main and important feature in the modern drill. Previous to the adoption of the lever system (which originated with the so-called "Suffolk Drill"), all the coulters were fixed in one transverse beam; whereas in this system each coulter is fixed to an independent lever.

Fig. 27, Plate 44, shows the bent levers D and D_1, secured at their fore ends to the transverse beam E, and jointed at F, whilst at their rear ends they are furnished with weights G; thus the coulters H and H_1, attached to the levers, are free to adjust themselves to the undulations of the soil, and deposit the seed at a uniform depth, this depth being regulated by the number of weights on each lever.

Too much attention can scarcely be paid to the durable construction of the joint F; but in many cases durability is sacrificed to cheapness of manufacture.

As a rule no means are provided for taking up the wear in the joint; but the writer has been induced to bring out an adjustable joint, illustrated by Figs. 30 to 32, Plate 46. The lever A at its forked fore end is furnished with a turned pin B, securely riveted to it. To the transverse wood beams C, cast-iron coupling lugs DD are attached by the bolt E and washer F. The couplings DD receive the lever-pin B. They are packed with wood packing I, and kept tight by the screws and nuts HH.

The coulters, by means of which the seed is deposited, are in Europe almost universally of the shape shown in Figs. 23 and 27, Plates 42 and 44, and have a cutting action; whereas in American drills, as shown in Fig. 26, Plate 43, they assume the shape of a hoe.

It should be remarked that no drill can be considered as generally useful, unless means are provided for regulating the depth to which the coulters penetrate the soil under all conditions.

In order that the coulters may clear themselves the more freely of rubbish, clods, and other impediments, they are usually placed alternately in advance of one another. Thus in Fig. 27, Plate 44, it will be seen that the coulter H is placed nearer to the joint F of the lever D, than the coulter H_1 to that of the lever D_1; it therefore follows that the weight G, on the tail end of the lever D, must not be so great as that on D_1; consequently it is customary to furnish the two sets of levers with two and three weights respectively. This arrangement, with a single beam, is still retained by Messrs. Garrett, Holmes, Gower, Reeves, and the writer's firm.

Some makers however adopt a plan designed by the late Mr. Richard Hornsby in 1850, and shown in Fig. 24, Plate 42, namely that of using two transverse beams, to which the coulter-levers are attached, instead of one. The beam E_1 is placed in advance of the beam E by a distance equal to that between the coulters H and H_1; and in this case the levers D and D_1 are both alike and equally weighted. This arrangement is undoubtedly correct in theory, but the writer finds that in practice it has its drawbacks. It also necessitates the use of iron for the transverse beams, whereas in the heavy land of the corn-growing districts wood beams are unquestionably preferable, as giving much greater rigidity with the same weight.

4. The conductors should be of such construction as to ensure that the passage of the seed shall not be hindered in its descent from the seed-box to the soil, and also that they shall adjust themselves to all positions of the coulters.

There are four kinds in use :—

(1) The ordinary funnel-shaped conductors, shown in Fig. 23, Plate 42;

(2) The india-rubber conductors shown in Fig. 26, Plate 43, as brought out by the late Mr. Richard Hornsby in 1850, and now used by the American makers;

(3) The telescopic conductors, brought out by the writer in 1864, as shown in Fig. 33, Plate 46;

(4) The ball-and-socket jointed conductors, adopted by Messrs. Woolnough, Figs. 24 and 34, Plates 42 and 46.

The telescopic conductor, Fig. 33, consists of three tubes: the lower one A resting upon the spherical cup D, receives the inner tube B; and the latter, being furnished at the top with a concave rim, is supported by the outer tube C. This outer tube also serves the purpose of excluding dirt and other extraneous substances from entering the lower tube. The lower part of the spherical cup D terminates in a socket, which passes through the coulter-lever into the coulter E.

The ball-and-socket jointed conductor of Messrs. Woolnough, Fig. 34, Plate 46, is in three parts; the upper part A, which is funnel-shaped, is connected to the seed-box, and the other parts are tubular.

5. The apparatus for steering the drill is of two kinds:—

(1) The Hind Swing steerage;

(2) The Fore Carriage steerage.

The Hind Swing steerage is an arrangement by means of which the lever-beam is made to move in a direction transverse to that in which the machine is travelling: it is worked by the attendant behind the drill. This system however is being fast supplanted by the Fore Carriage steerage, and is now only used in a few localities.

The Fore Carriage steerage, shown in Fig. 27, Plate 44, is in general use all over Europe, with various modifications. Fig. 29, Plate 46, shows a plan of it, and also Messrs. Woolnough's arrangement for steering the same by mechanical means. In the ordinary way the steerage is furnished with steadying chains P, shown dotted, which are strained from the front part of the drill-frame to the steerage-axle; but in Messrs. Woolnough's arrangement it will be seen that the vertical drum V, actuated by the lever-handle W, is connected by means of the pitch-chain X to the axle-uprights Z, and thereby the drill is steered.

Other arrangements have from time to time been introduced, but the foregoing are the only ones that are in any particular request at the present day.

Abstract of Discussion on Machinery for Sowing Seed.

Mr. SMYTH exhibited a model of the early Suffolk drill, made forty years ago by his father, who was now in his seventy-fifth year, and was unable to be present in consequence of illness. The gearing was somewhat primitive. The height at which the seed-box was fixed, in order to bring the cog-wheels into proper gearing, was regulated by an upright bar, with holes into which a pin was placed. At the present day that would be considered very rudimentary, but no doubt when it was first made it was considered a very good design. Another point was that the back part of the frame was of wood 3 in. thick, which necessitated the wheels running very much on an incline. That had been replaced, as in Fig. 23, Plate 42, by an iron side-plate. The lever system however was pretty much as it had descended from his grandfather in the year 1800, when he made the first Suffolk lever drill; and it remained so to this day. Considering the facilities possessed by engineers at the present day, and the disadvantages which their forefathers experienced, they might be very thankful that their fathers had done so much with far inferior facilities.

When asked to prepare this paper, he had thought of extending it to a greater length; but he found it necessary to circumscribe it as much as possible, in order to make it interesting to all, and to bring before the Institution all the chief systems that were in operation. It was perhaps right that he should now state his opinion as to what systems were to be considered the most advanced. He had not attempted to describe fully a large variety of machines, because that would have required too long a time; he had restricted himself to bringing forward systems that were fairly representative of the arrangements now in use. But it was not unnatural that many should say to him as a manufacturer "Why do you stick to a certain system?" One chief reason was that in his experience he had found it necessary to produce for England and the colonies an article that would go everywhere and do everything.

On the other hand, in some countries they only sowed two or three kinds of grain; thus their American friends required the machines only for drilling grain, chiefly wheat, as that was the principal thing they had to do; whereas in England, with their more advanced state of cultivation, farmers wanted a drill that would drill all kinds of grain, also beans and peas, and all kinds of seeds, and that would be capable of easy and quick adjustment in the field to suit these varieties. That condition of things he failed to find in the machine shown in Fig. 1, Plate 36; it was not a system that could be considered satisfactory with regard to sowing seeds and regulating their quantity. The American machines also met with some difficulty in passing from grain to small seeds, which he maintained was a very serious disadvantage. Again the indented-disc machines of Mr. Sack, Figs. 12 and 13, Plate 37, although they were being used in large numbers, were better adapted for level land than for hilly land. The indented discs, if they were inclined slightly in going along the side of a hill, were certain to throw some seed sideways away from the hopper; while, in going up and down hill, very great care was needed in adjusting the slide through which the seed passed from the chamber A to the cup-wheel C through the opening B. Consequently he himself pinned his faith as a manufacturer on the side-cup system, represented in Figs. 15 and 16, Plate 38. By that system they could drill anywhere—along a hillside, or up hill, or down hill; they could adjust the machine for any kind of grain or seed in two minutes; and they could take all the cup-wheels out and replace them with others in a very short time. So that with regard to delivery English makers must adhere to the side-cup system, as being the best. At the same time he admitted that by so doing they stood at a disadvantage in regard to their colonial customers, as compared with the American and other systems, which were cheaper. Still, as the side-cup system only enhanced the price of the machine by 20*s.* or 30*s.*—and that a machine which practically lasted for life—he thought it would be folly in English manufacturers to recede from what was really best in their estimation, and that for the sake of so small a difference.

Another point, which was being discussed in the trade considerably

at the present day, was the manner in which the seed should be deposited in the soil. The Americans preferred a coulter shaped like a hoe or harrow, as in Fig. 26, Plate 43. It had the advantage that it broke up the soil, so that in many cases the field would not require to be harrowed afterwards. He had tried an American machine himself on his own farm, because as a manufacturer he liked to know the ins and outs of everybody's machine; but he had found a difficulty in getting the hoes to penetrate in all conditions of soil. He knew that in England it was being adopted on light lands, and he believed with a certain amount of success. Still, he thought there was always a difficulty in getting the hoes to penetrate to a uniform depth. In drilling some kinds of grain, for instance barley or small seeds, the hoes would penetrate too deep; therefore they must be suspended partially by chains in order that they might not penetrate too far, and then they virtually ceased to be lever drills, for the reason that, being suspended from the beam, they could no longer properly follow the undulations of the ground. In consequence of this he had come to the conclusion that no drill could be considered thoroughly satisfactory, unless the levers D, Fig. 27, Plate 44, were capable of receiving coulters of the shape shown at H, and also hoes or coulters of a shape similar to that shown in Fig. 26—an alternative arrangement which he had adopted, more especially for the sake of his colonial customers.

There was another point connected with bringing seed to the soil, namely the conductors. In the old funnel-shaped conductors, Fig. 23, Plate 42, it would be seen that there was a liability for dirt to fall in and block the conductor. That had been partially obviated by Messrs. Hornsby's india-rubber arrangement, Fig. 26; also by Mr. Woolnough's conductors, Fig. 24, Plate 42. Still the pipe on the lever, it would be seen, was open, and consequently there was still the liability of dirt getting in, as was also the case in the American systems. That, he considered, was always a defect; and it had led him, being spurred on by French competitors, to bring out the telescopic conductor, Fig. 33, also shown in the side view of the drill, Fig. 27. There it would be seen that by no possibility could any dirt or wet get into the tube to block it; and when once the seed

came in at the top, it was bound to pass right through into the soil. He wished, before sitting down, to express his thanks to the various gentlemen who had assisted him with information &c., and particularly to Mr. Woolnough for furnishing the pencil drawing of Fig. 24, Plate 42.

Mr. Wm. Anderson regretted there were no gentlemen present who had used the implements in question as actual farmers; but perhaps, as Engineer to the Royal Agricultural Society, he came near to having done so. In the year 1874 it became his duty to test a very large number of drills at the Bedford show; and to give an idea of the wide extent of the subject, he might mention that there were twelve classes of drills tested, and that the judges' reports occupied thirty-four pages in the Journal of the Royal Agricultural Society for 1874, pp. 629–662. Those who took an interest in the subject would find there a full account of a very interesting series of experiments. The trials occupied several days, and immense care and pains were taken with them. The principal thing to which the judges addressed their attention was the regularity of delivery by the various coulters, and that each row sown should receive approximately the same quantity of seed. It was astonishing what differences there were in this point, especially on sidelong ground. None but the cup-drills were of any use from that point of view. Even with these, there was a difference of as much as 40 lbs., or a bushel of seed, to an acre, between one row and another. Although apparently everything was exactly alike, one set of cups would deliver very much more than another. The judges awarded the medal to the drill which acted best in that respect. Another defect was the weakness of the coulters, and their inability to penetrate the ground deep enough to deposit the seed a proper distance from the surface. There was severe competition in the manufacture of drills, and the tendency therefore was to reduce the parts more and more to the utmost possible lightness of section. The consequence was that many of them were unable to penetrate the ground, especially in hot and dry weather when it was very hard. Another defect was that very few of the seed-boxes were adapted to keep out the wet. They did all very well when sowing in dry

weather; but in wet weather the water got into the seed-boxes, and that complicated matters to a great extent; in fact many of the drills were quite disabled from the effect of the water. There was one drill, not mentioned in the paper, which gave the best delivery of all, and obtained the prize for sidelong ground. Under the seed-box, as shown in Fig. 14, Plate 37, were two small drums, which worked a pitch-chain travelling horizontally across the opening in the bottom of the seed-box; and the opening itself was fitted with a regulating slide. The links of the chain formed the cups. There was no mechanism whatever inside the seed-box, but the seed was distributed equally to each conductor, whether the drill was going up and down hill, on sidelong ground, or on a level. The delivery was remarkably exact. In different trials with this chain drill, when going at a slow pace, the quantities of seed delivered from each of the five apertures in the seed-box were $17\frac{1}{2}$, $17\frac{1}{4}$, $17\frac{1}{2}$, 16, $16\frac{1}{2}$ oz. respectively; and in going at a gallop they were 15, 15, 15, 13, $13\frac{3}{4}$ oz. respectively (Royal Agricultural Society's Journal, 1874, p. 642). He did not know why that system had not been further extended, as it seemed remarkably simple and effective.

Mr. SMYTH said, in reply to Mr. Anderson's remarks, that his firm had not competed at the Royal Agricultural Society's trials since 1854; but he could probably explain why the cup system did not always give uniform results, and the reason was that the cups were sometimes not set properly. In Paris, in 1878, a drill that was set by himself in the Exhibition went into the field just as it left his hands, and it got on remarkably well, each row being equally sown. But if the cups were not set at a uniform angle to the diameter of the wheel, so that every cup stood precisely alike, the consequence would be that one cup would begin delivering earlier than another, and the sowing would thus be unequal. But he would engage to make a side-cup drill as perfect in regard to delivery as any other system that had been brought out. In his own arrangement, Figs. 17 and 18, Plate 39, there was a shoot which was set close to the cup wheel, and the result was that the wheel must be slanted considerably—quite beyond what could occur on any hillside—before the seed would fail to fall into

the conductor. In many arrangements, the hoppers shown in Fig. 15 were kept some little distance away from the cup wheel; consequently when the drill was on the side of a hill falling towards the left, the seed from the right-hand cup would fall between the wheel and the hopper. That would naturally create a difference as to the quantity of seed sown, because it was merely a question of what went into the hopper and what did not. The cup itself was of a spherical shape, so that it mattered not what the inclination was, there was the same spherical cup to take up the same quantity of seed.

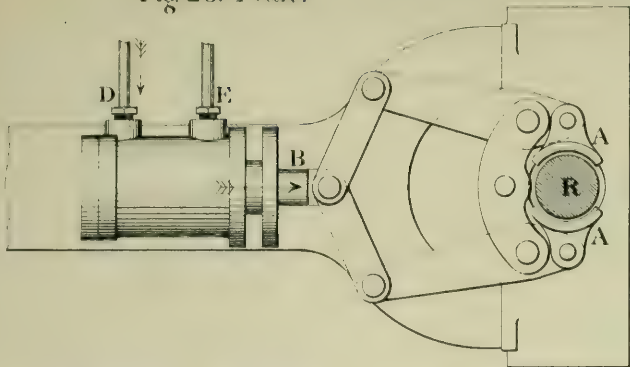
With regard to the strength of the levers, he would admit that generally speaking Mr. Anderson was right,—the majority of levers were not made sufficiently strong. In Fig. 23, Plate 42, was shown a lever made by his firm. The front part was made of 1 in. square iron, and the hinder part of $\frac{7}{8}$ in. round. But a common plan was to make the front of $\frac{7}{8}$ in. square, and the back of flat bar about $1\frac{1}{4}$ by $\frac{3}{8}$ in. The result was that a man could almost bend the hind ends of two adjacent levers together till they touched; and when the pressure came upon such a lever by the cross-bar K, Fig. 27, it began to yield sideways, and of course would not penetrate. For that reason his firm used nothing but square and round iron.

As to wet getting into the seed-box, of course there was that liability, but it might be easily remedied if required. Drill-makers however did not believe that drilling was ever done when it was raining much; as a rule, farmers would tell them that the horses ought then to be in the stable. If the judges of the Royal Agricultural Society laid much stress upon that point, he thought they were wrong (with all deference to them), because it was a matter that could be so easily remedied if needed. With regard to Messrs. Dening's arrangement, referred to by Mr. Anderson, the reason why it had not found favour was that it was not sufficiently durable. It was made with double-link jack chain, and there was a groove just at the bottom of the seed-box, through which the chain had to pass. It was easy to conceive that dirt &c. might get into the eyes of the chain, and cause them to be strained; and as a matter of fact they would not stand the wear.

The President said he was sure the thanks of the members were due to Mr. Smyth. They would agree that he had almost exhausted his subject, and had brought it forward in a very clear manner. He could not help saying that Mr. Smyth's criticisms on other makers had also been very fair and candid. They had also to thank him for the numerous diagrams, which it appeared he had drawn himself with his own hand.

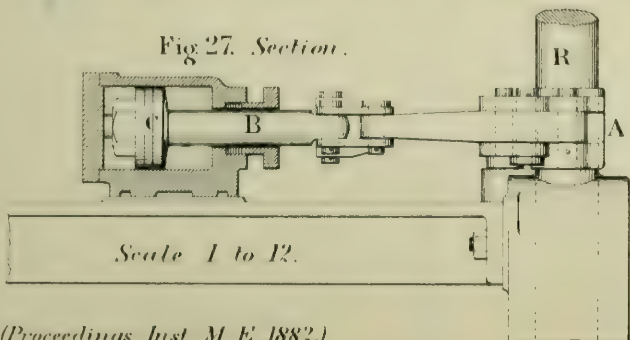
HYDRAULIC LIFTS.

Fig. 26. *Plan.*



Safety Brake for Direct-acting Lifts.

Fig. 27. *Section.*



(Proceedings Inst. M. E. 1882.)

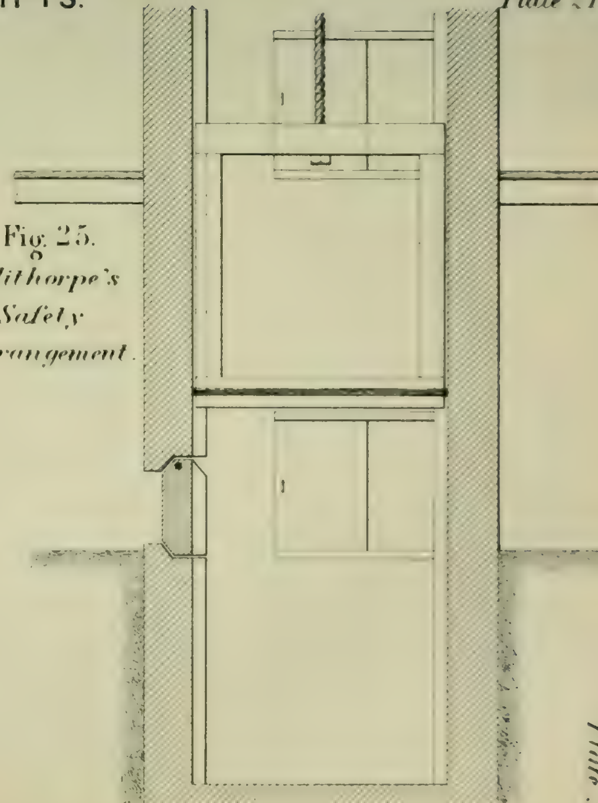
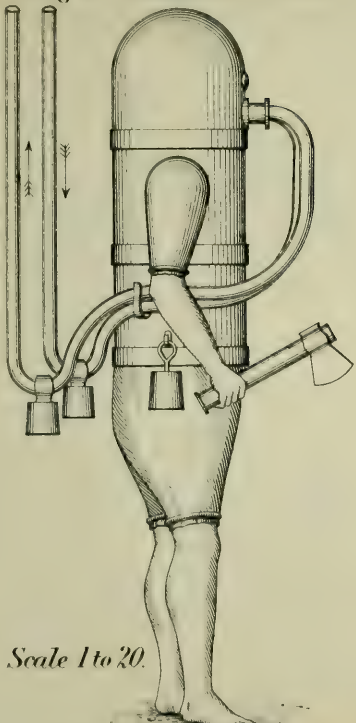


Fig. 25.
Ellithorpe's Safety Arrangement.

Plate 21.

DIVING APPLIANCES.

Fig. 1. *Kleingert's Dress.*

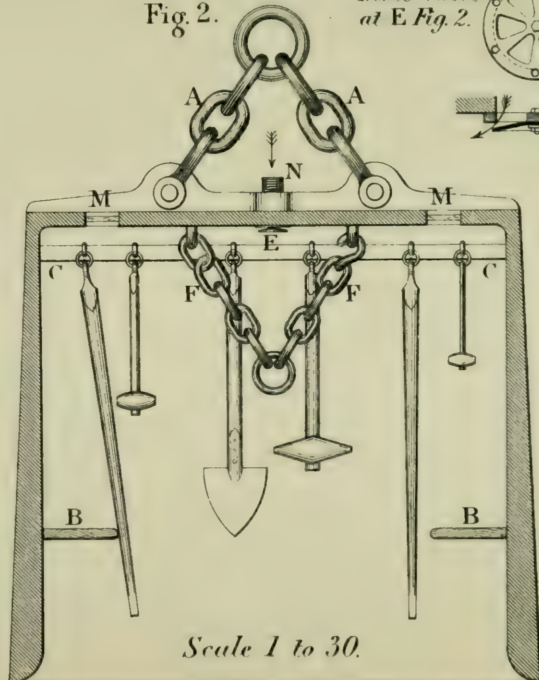


Scale 1 to 20.

(Proceedings Inst. M. E. 1882.)

Rennie's Diving Bell.

Fig. 2.



Scale 1 to 30.

Fig. 3.

Inlet Valve at E Fig. 2.

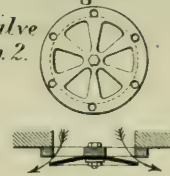
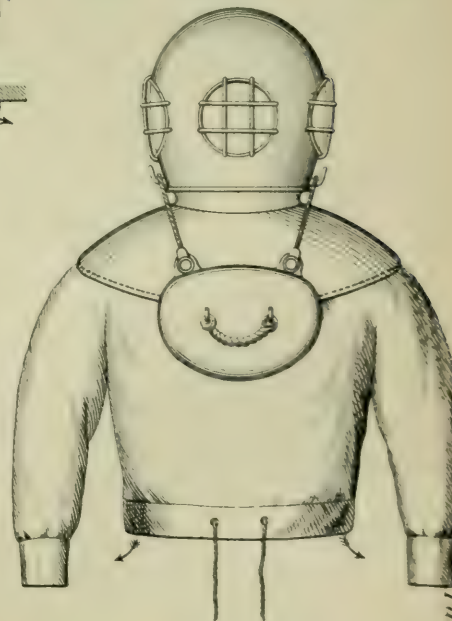


Fig. 4.

Siebe's Open Diving Dress.



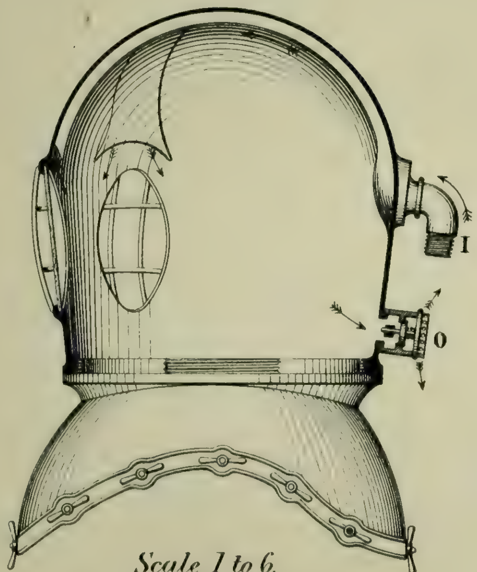
Scale 1 to 12.

Plate 22.

DIVING APPLIANCES.

Fig. 5.

Siebe's Close Helmet.

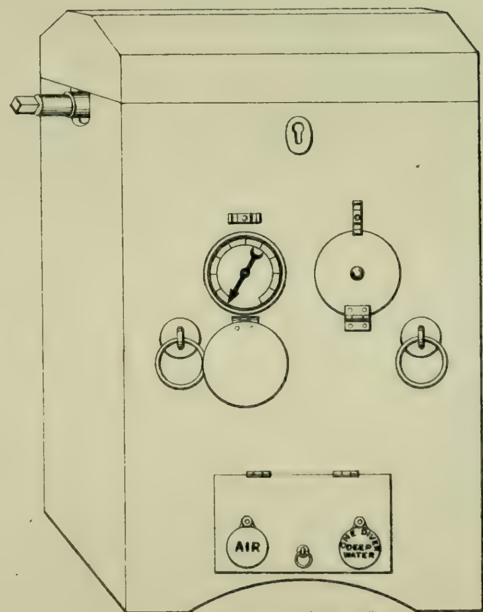


Scale 1 to 6.

(Proceedings Inst. M. E. 1882.)

Fig. 8.

Air-Pump Case.



Scale 1 to 12.

Fig. 11.

Plan of

Air-Valve Lever

Scale 1 to 8.

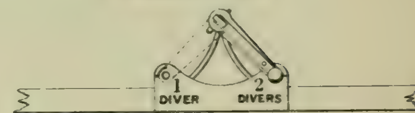


Diagram of

Air-distributing Valve.

Fig. 9. Fig. 10.

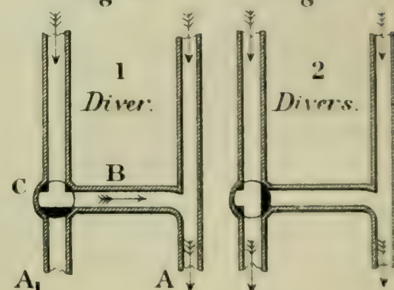
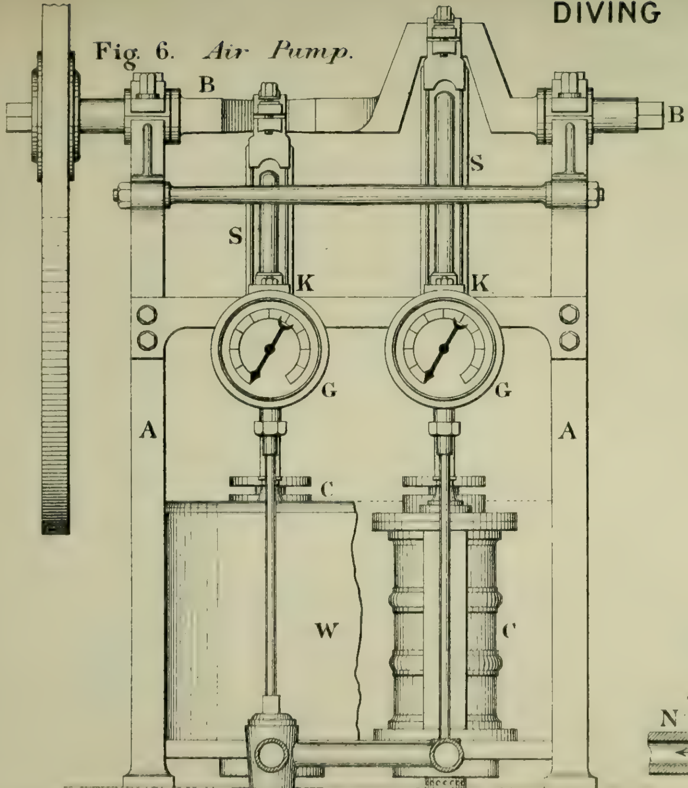


Plate 23.

DIVING APPLIANCES.

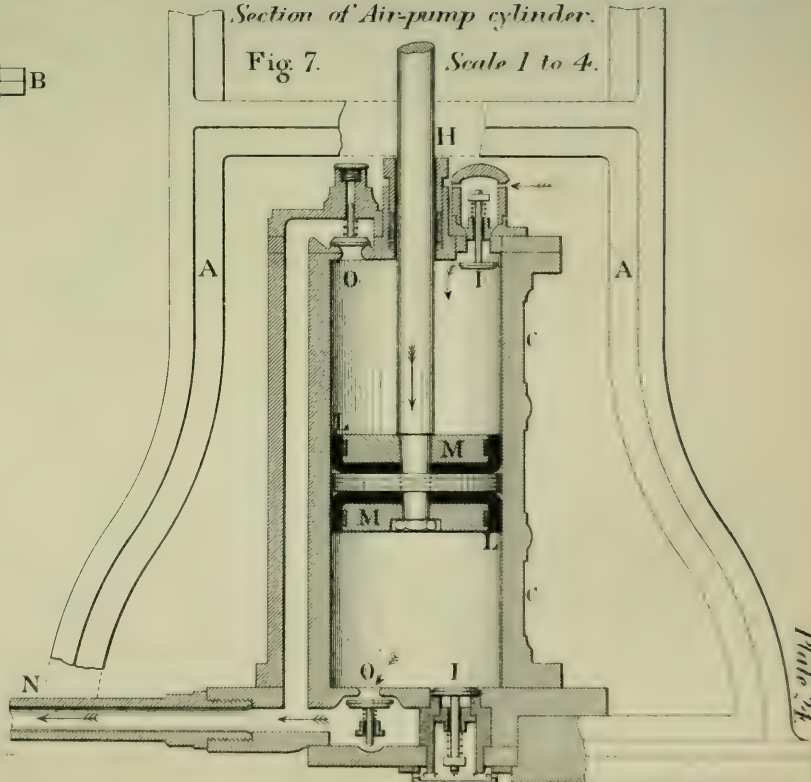
Fig. 6. *Air Pump.*



Scale 1 to 8

Section of Air-pump cylinder.

Fig. 7. *Scale 1 to 4.*



(Proceedings Inst. M. E. 1882.)

DIVING APPLIANCES.

Improved Helmet.

Fig. 12. *Elevation.*

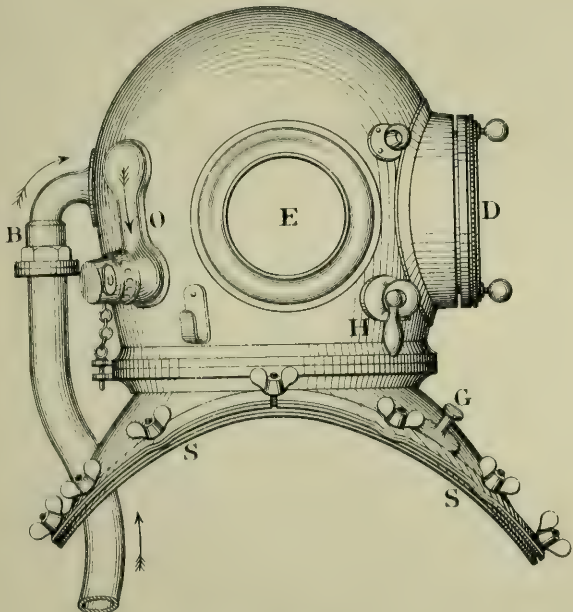


Fig. 13. *Section.*

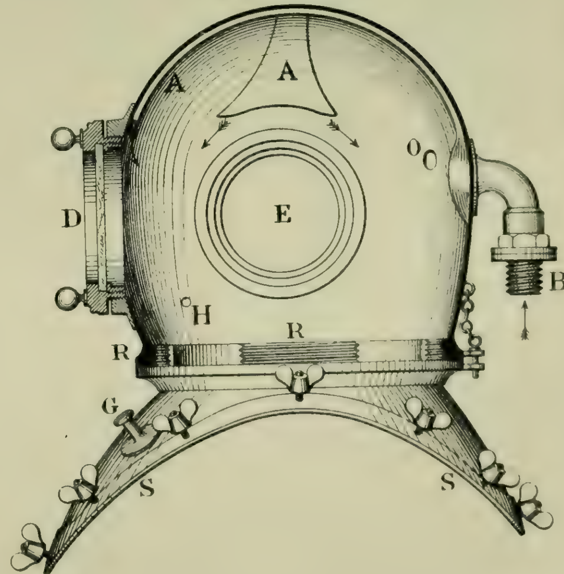
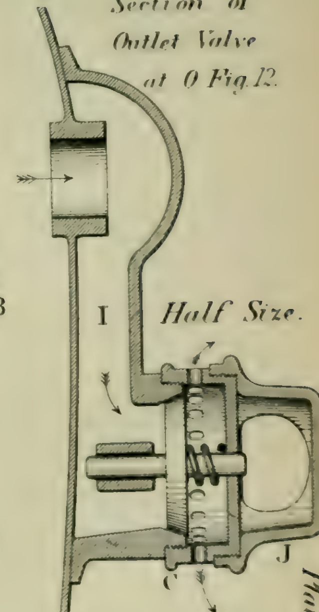


Fig. 14.

Section of Outlet Valve at O Fig. 12.



Scale 1 to 6.

(Proceedings Inst. M. E. 1882.)

Plate 25.

DIVING APPLIANCES.

Fleuss' Breathing Apparatus.

Fig. 15.

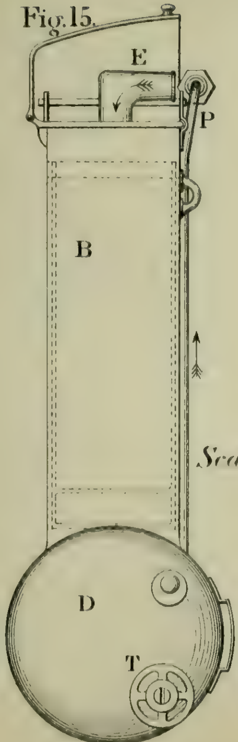
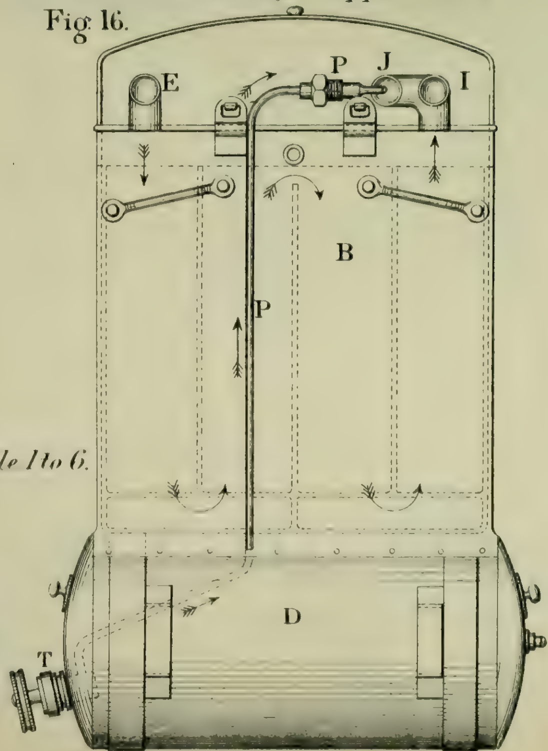


Fig. 16.



Scale 1 to 6.

Fig. 17.

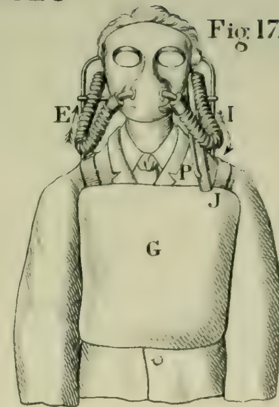


Fig. 18.

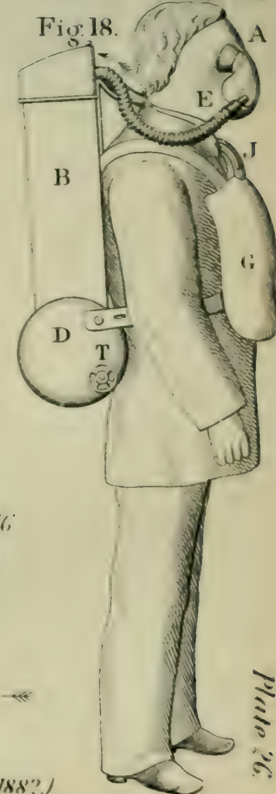
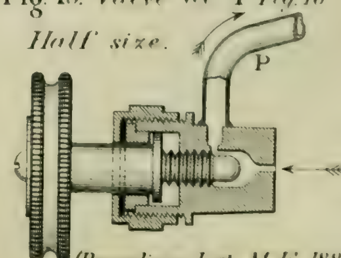


Fig. 19. *Valve at* T *Fig. 16*

Half size.

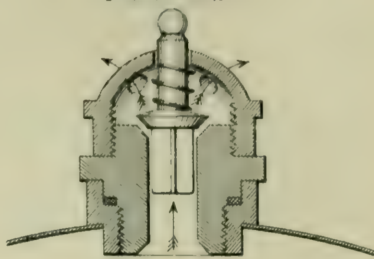


(Proceedings Inst. M. E. 1882.)

Oxy-hydrogen Safety-Lamp.

Fig. 20.
Section of Lamp.
One third full size.

Fig. 21. *Valve at* O *Fig. 20*
Full size.



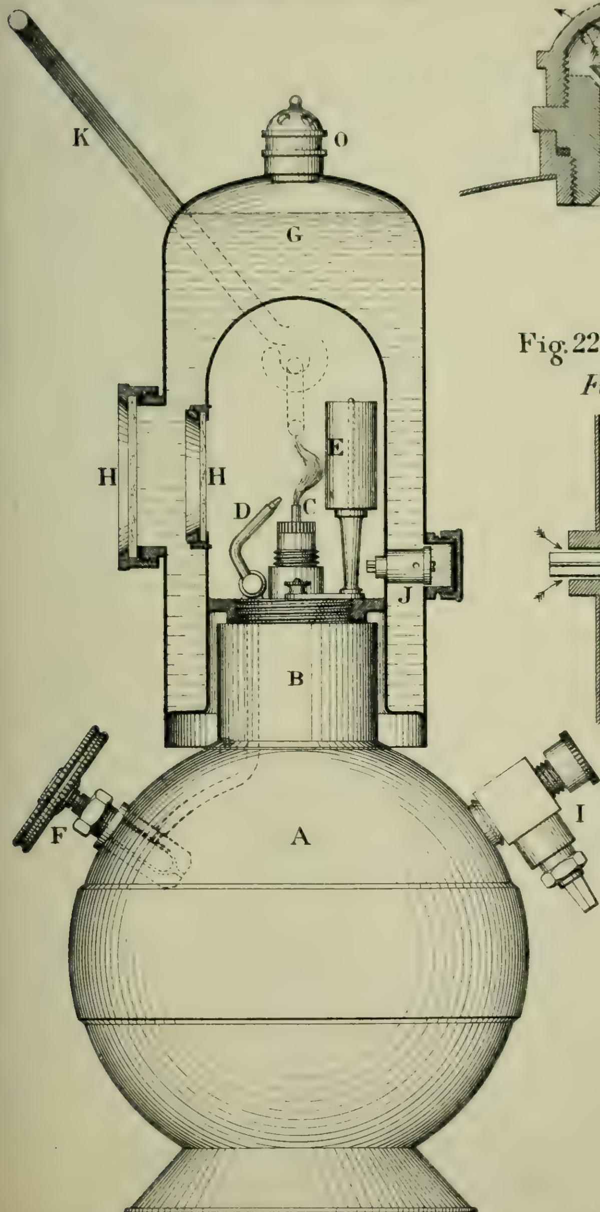
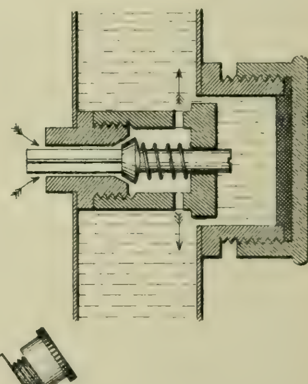


Fig. 22. *Valve at* J *Fig. 20.*
Full size.



One third full size

MOVABLE - FULCRUM HAMMERS.

Planishing Hammer.

Fig. 1.

Side Elevation.

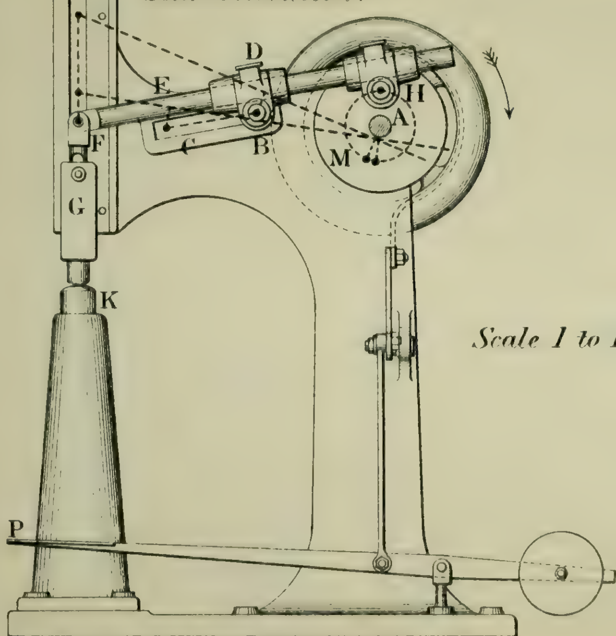
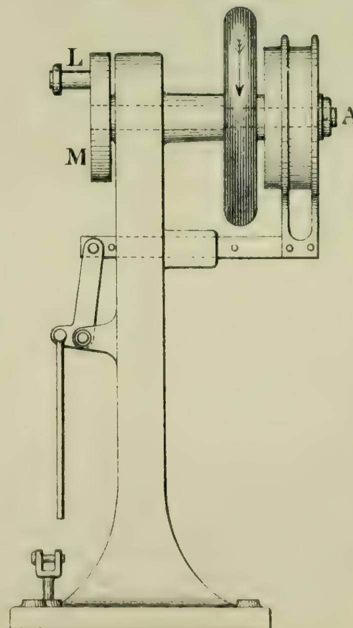


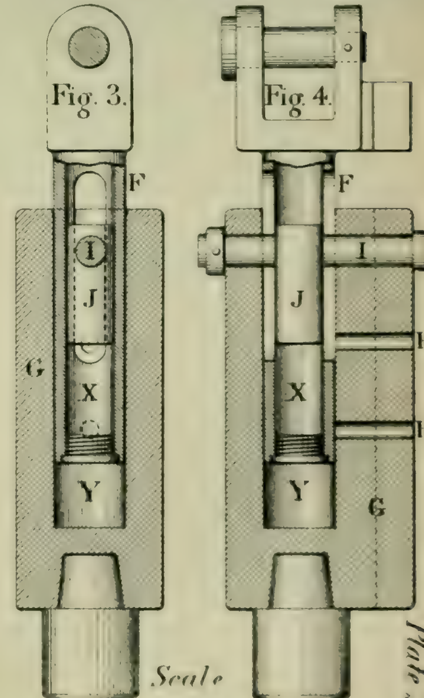
Fig. 2.

Back Elevation.



Scale 1 to 16.

Sections of Hammer-head.



Scale 1 to 4.

(Proceedings Inst. M. E. 1882.)

Plate 28.

MOVABLE-FULCRUM HAMMERS.

Medium-size Forging Hammer.

Fig. 5. *Front Elevation.*

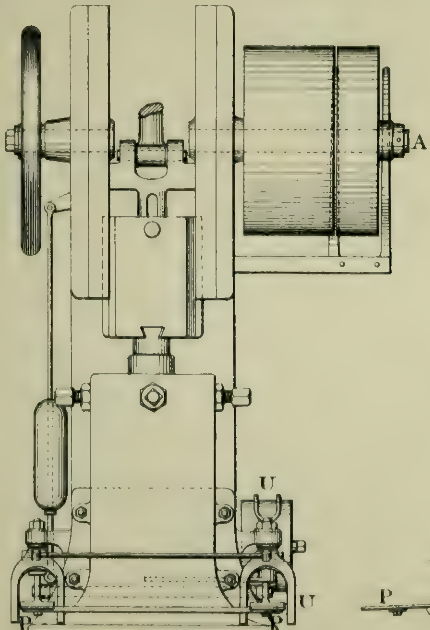


Fig. 6. *Side Elevation.*

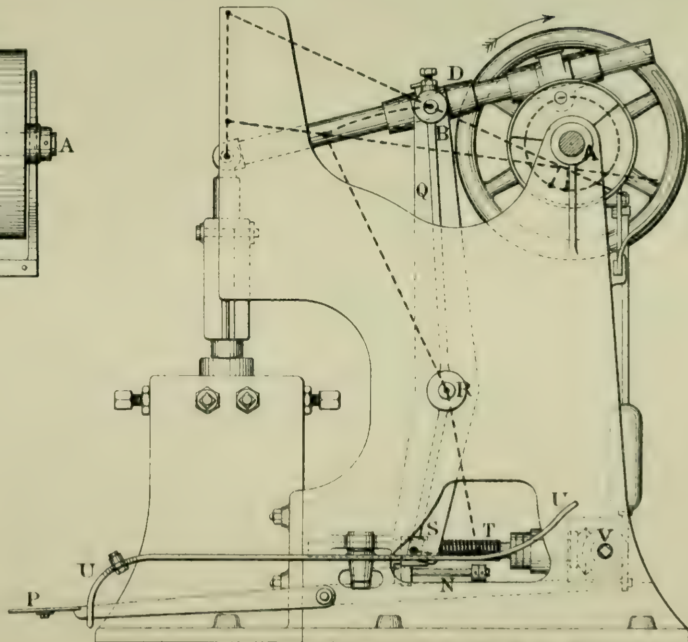
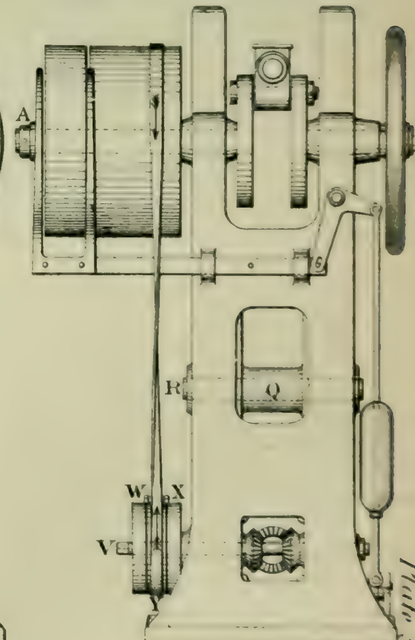


Fig. 7. *Back Elevation.*



(Proceedings Inst. M. E. 1882.)

Scale 1 to 20.

Plate 29.

Fig. 1.
Cartwright's Machine.

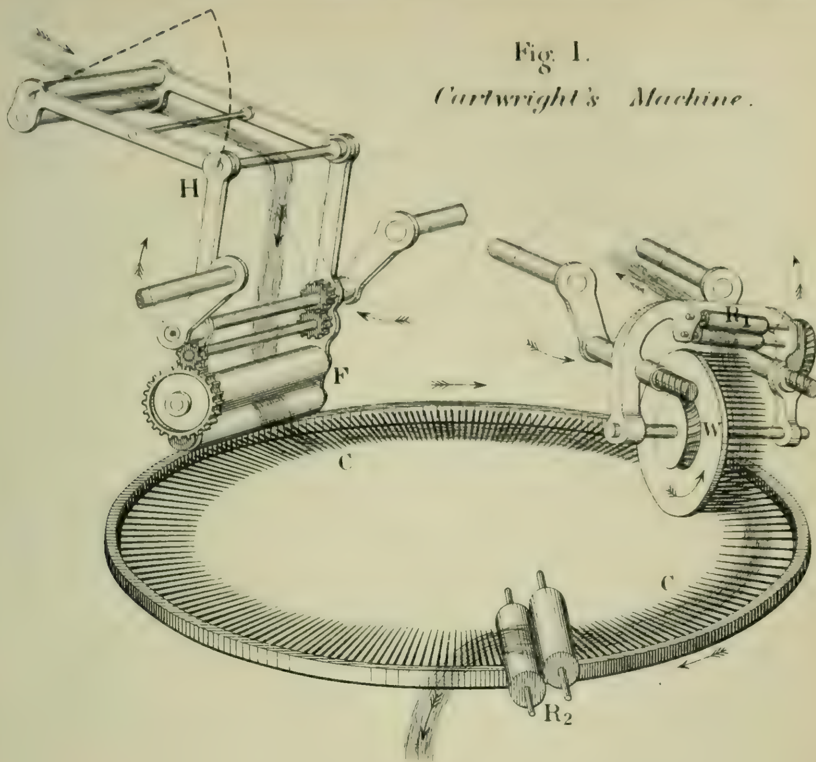
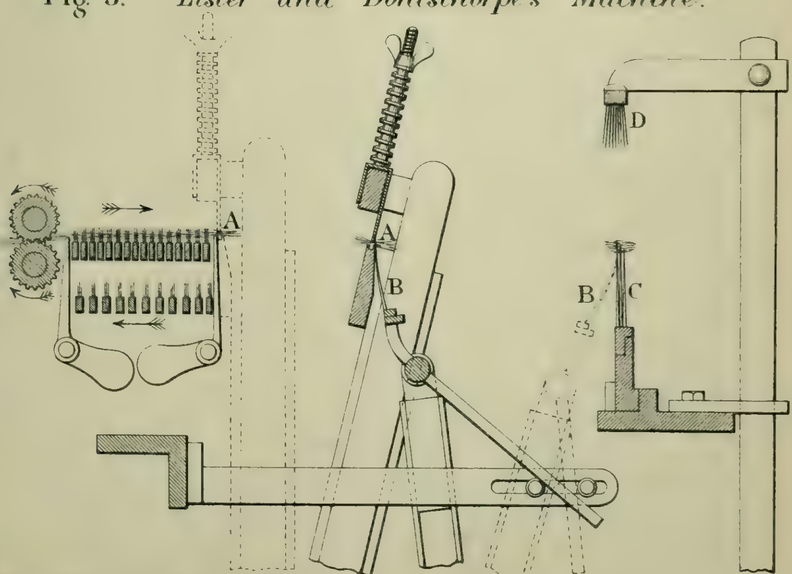


Fig. 3. *Lister and Donisthorpe's Machine.*



WOOL-COMBING MACHINERY.

Godart's or Collier's Machine.

Fig. 2.
Side elevation.

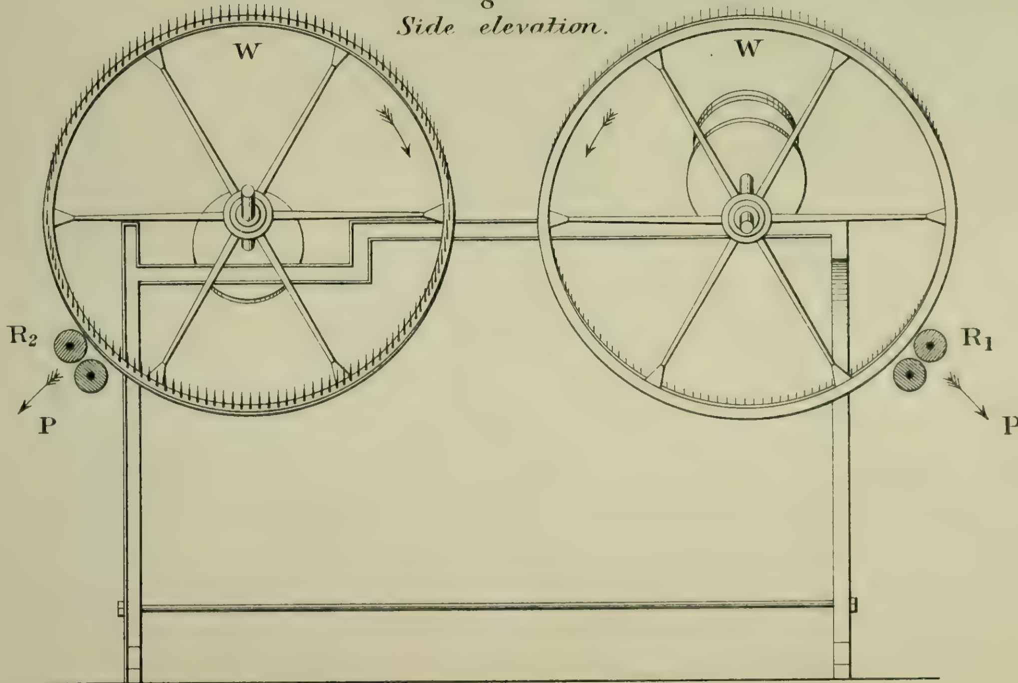
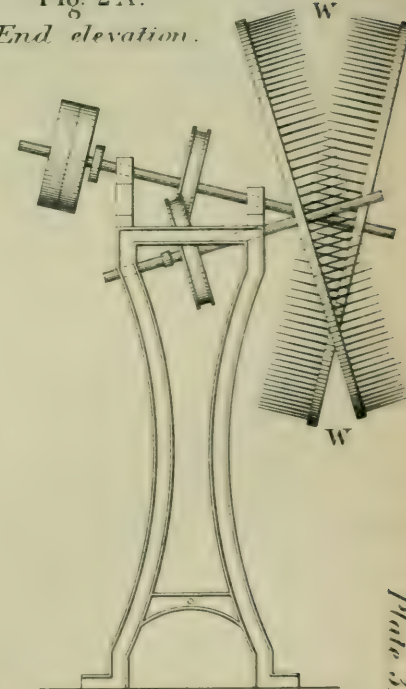


Fig. 2 A.
End elevation.

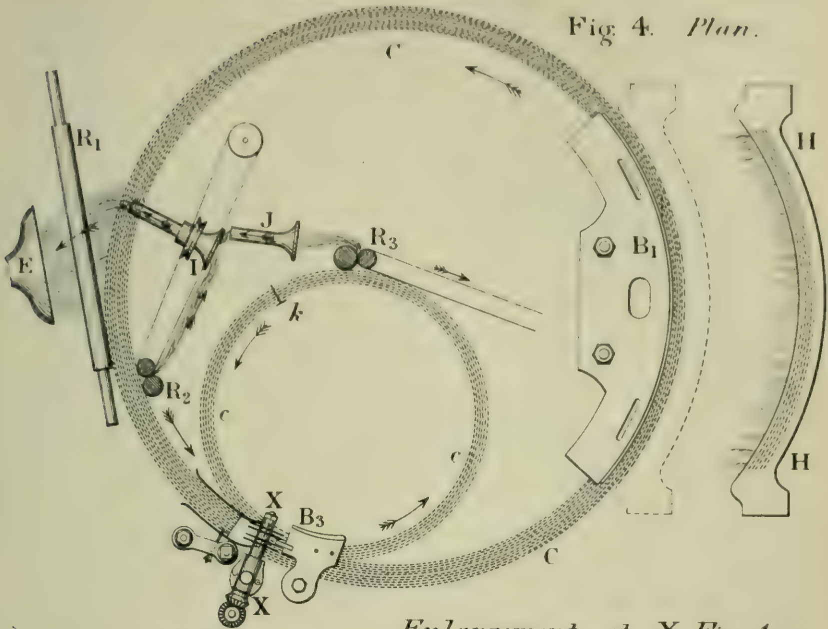


(Proceedings Inst. M. E. 1882.)

Plate 31.

Lange's Machine.

Fig. 4. *Plan.*



Enlargement at X *Fig. 4.*

Fig. 5. *Plan.*

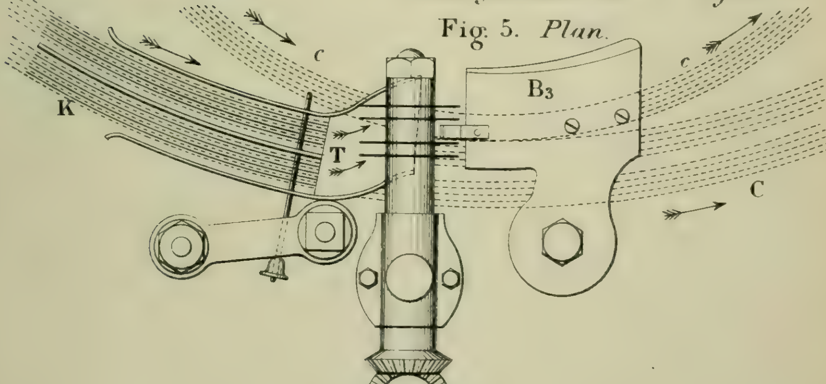
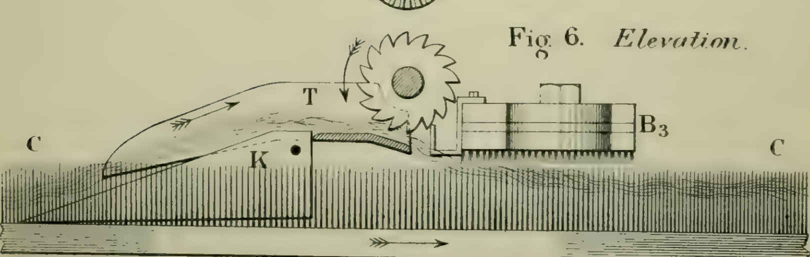
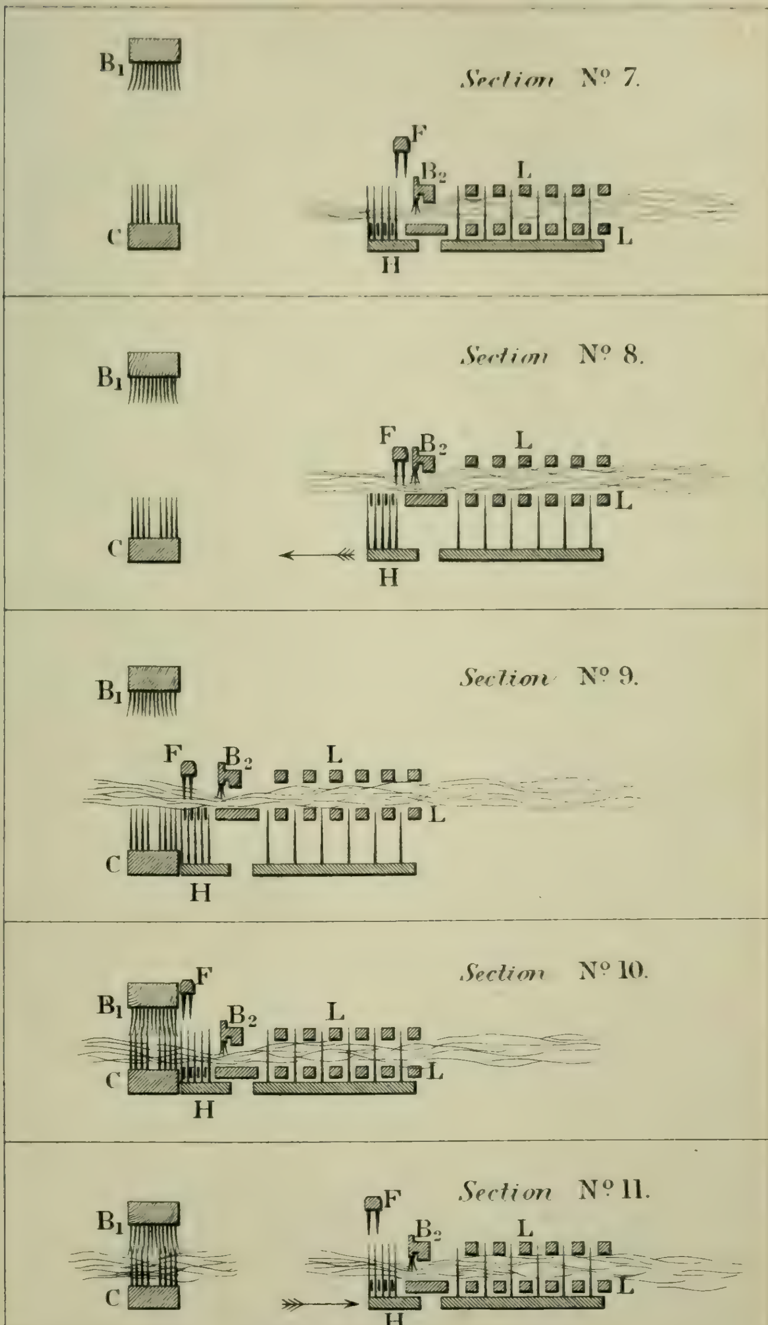


Fig. 6. *Elevation.*



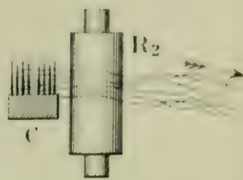
Sections showing action of Lange's Machine.



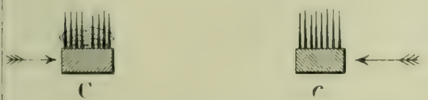
Sections showing action of Lange's Machine (continued)

Section No. 12.

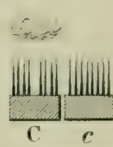
Section No. 13.



Section No. 14.



Section No. 15.



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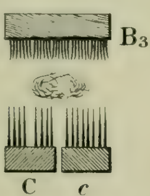

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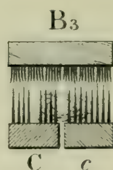

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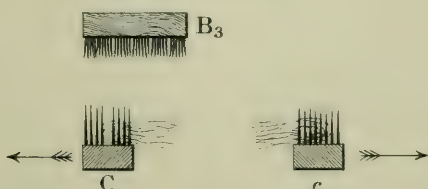

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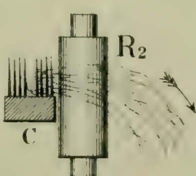
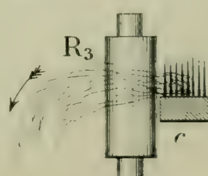


Section No. 20.



WOOL-COMBING MACHINERY.

General View of Lange's Machine.

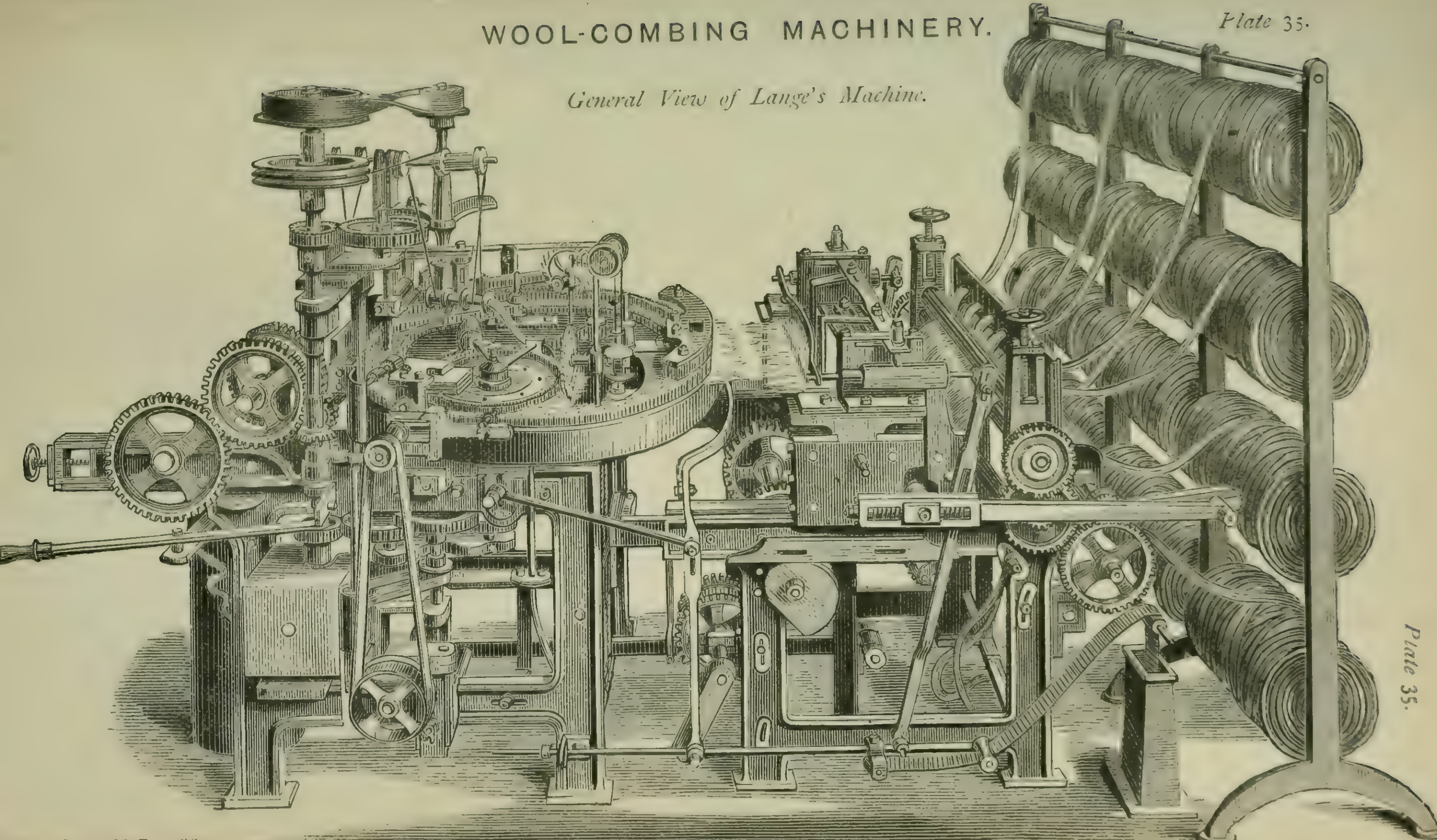
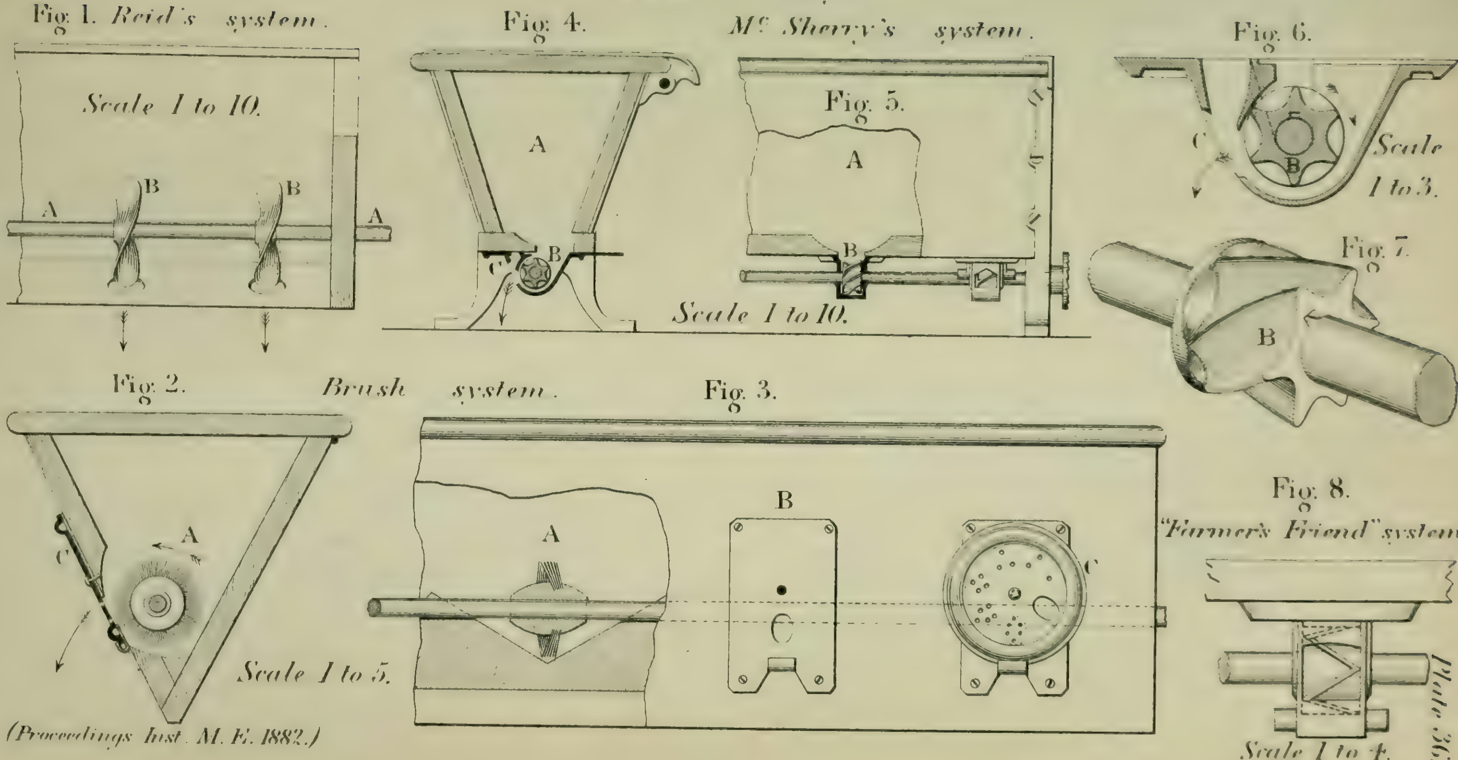


Plate 35.

SEED-SOWING MACHINERY.

Seed Delivery.



(Proceedings Inst. M. E. 1882.)

SEED-SOWING MACHINERY.

Seed Delivery.

Fig. 10. "*Superior*" *system.* Fig. 11.

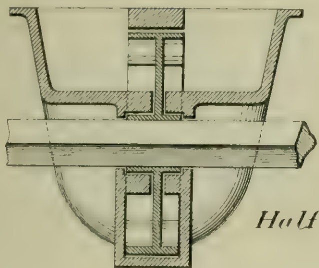
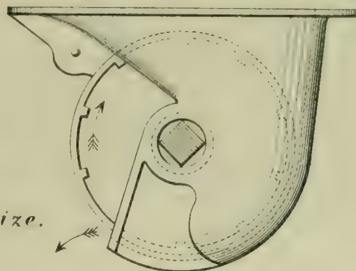



Fig. 9. "*Triumph*" *system.*

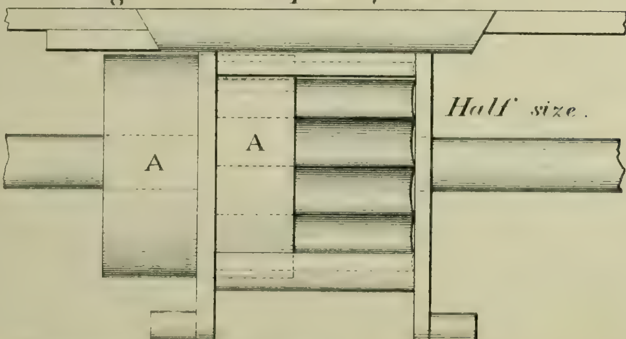


Fig. 14. *Dening's system.*

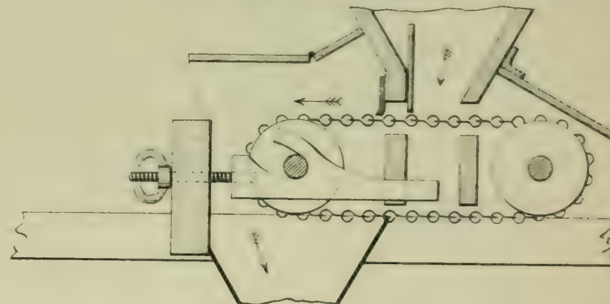
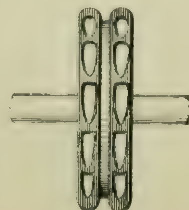
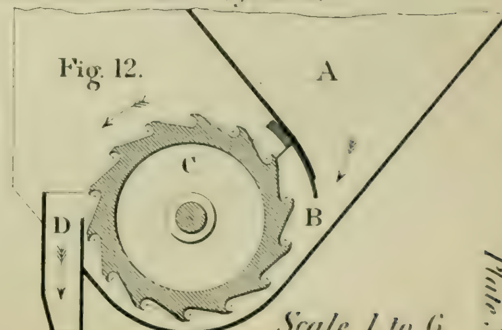


Fig. 13.



Indented-disc system.

Fig. 12.



Scale 1 to 6.

(Proceedings Inst. M. E. 1882.)

Plate 37

SEED-SOWING MACHINERY.

Side-cup Delivery.

Fig. 15. *Back Elevation.*

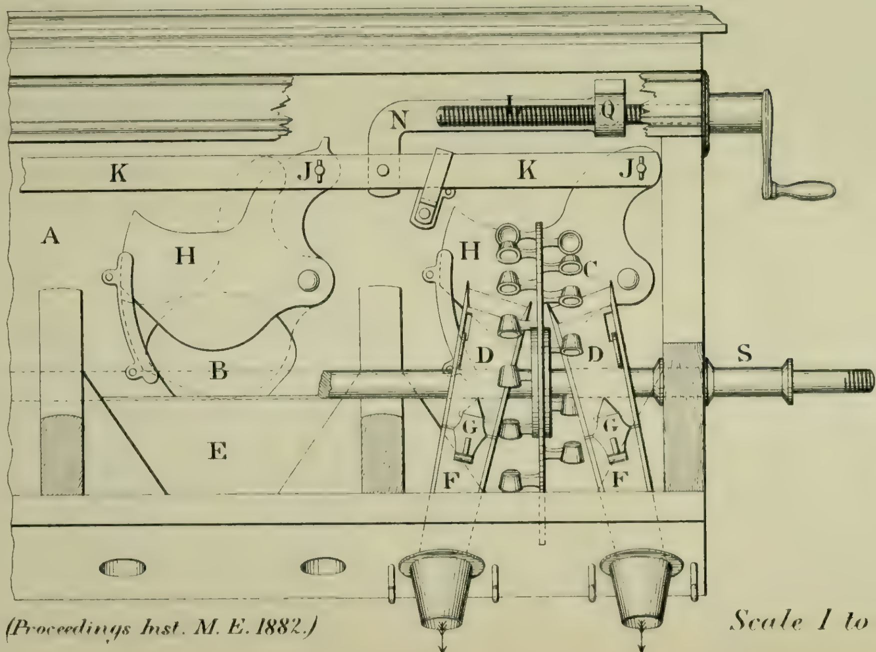
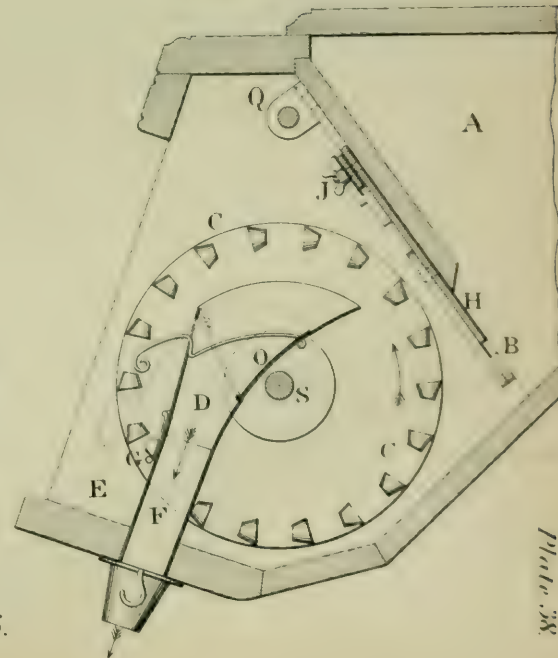


Fig. 16. *Side Elevation.*



Scale 1 to 6.

Plate 38.

SEED-SOWING MACHINERY.

Improved Side-Cup Delivery.

Fig. 17.

Longitudinal Section of Seed-box through a b, Fig. 18.

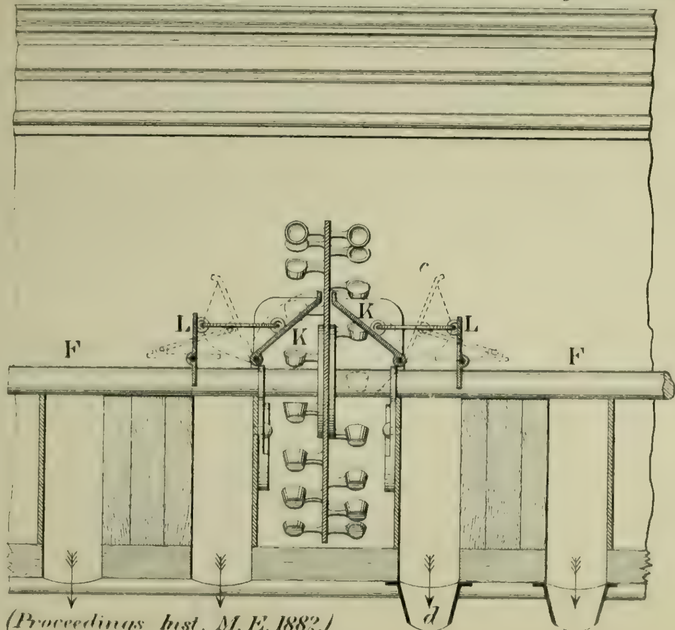
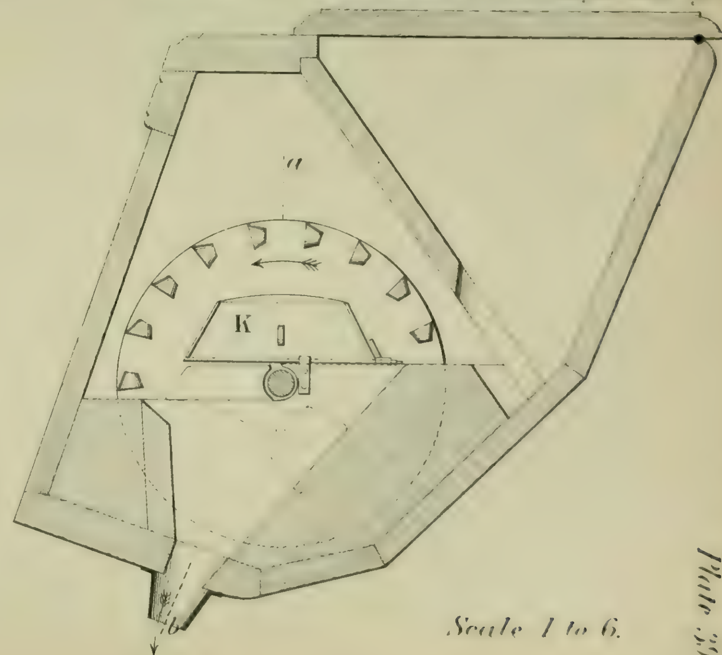


Fig. 18.

Transverse Section of Seed-box through c d, Fig. 17.



Scale 1 to 6.

(Proceedings Inst. M. E. 1882.)

Plate 39.

SEED-SOWING MACHINERY.

Feed-regulating arrangements.

Fig. 19. *Left-hand end.*

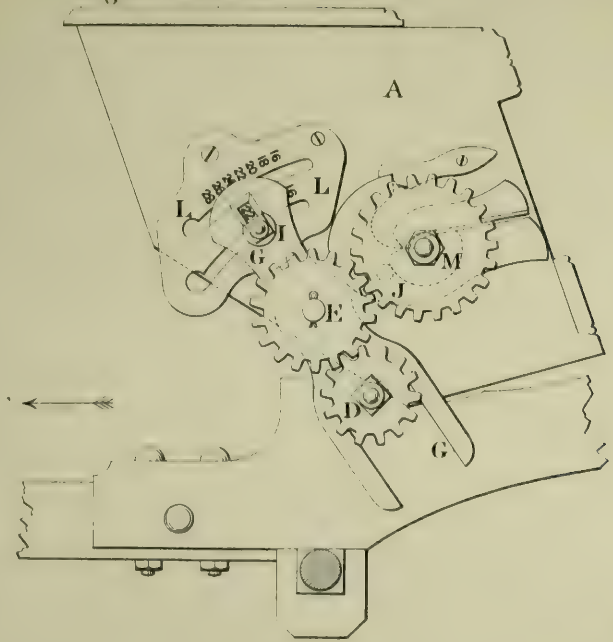
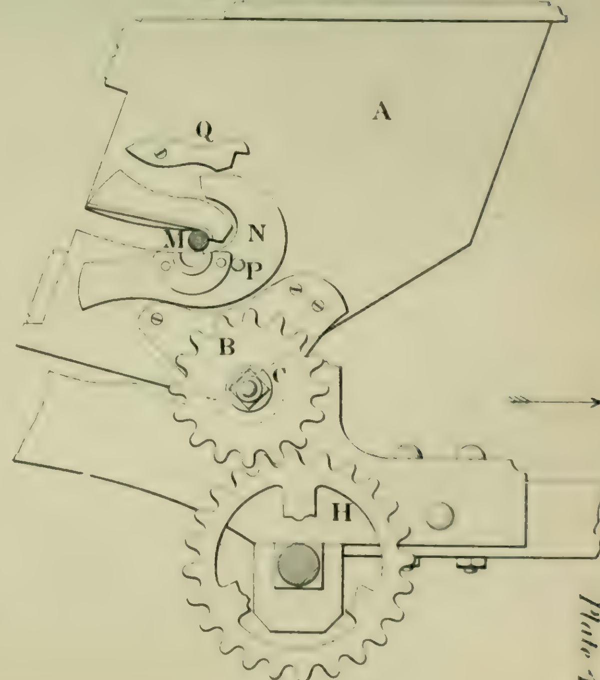


Fig. 20. *Right-hand end.*



Scale 1 to 16.

(Proceedings Inst. M. E. 1882.)

Plate 40.

SEED-SOWING MACHINERY.

Kaemmerer's Broad-cast Drill.

Fig. 21. *Back Elevation.*

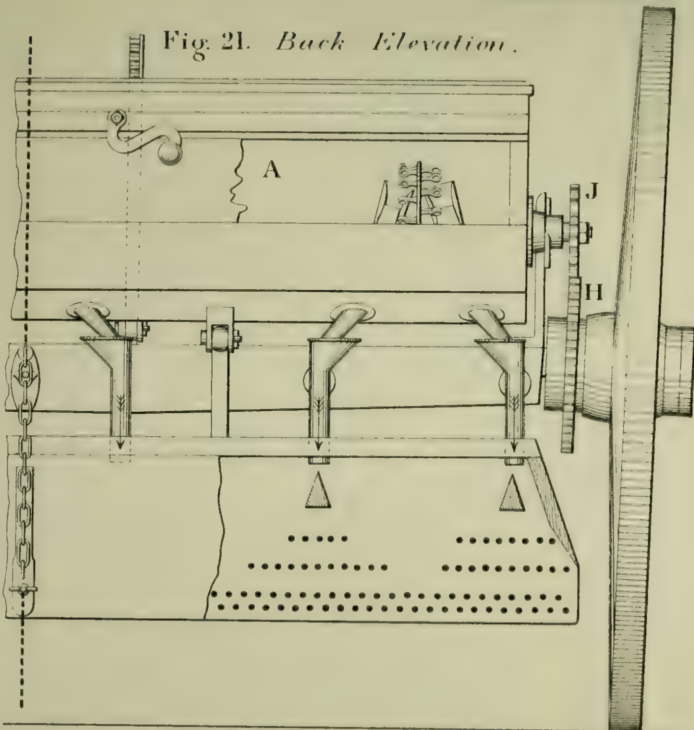
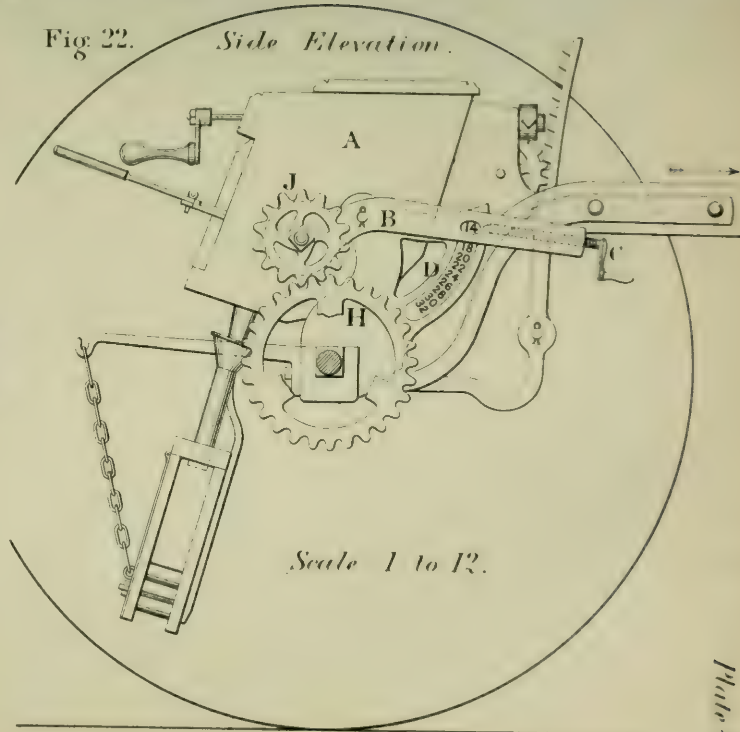


Fig. 22. *Side Elevation.*



Scale 1 to 12.

Plate 41.

Fig. 23. *"Suffolk" Corn-Drill.*

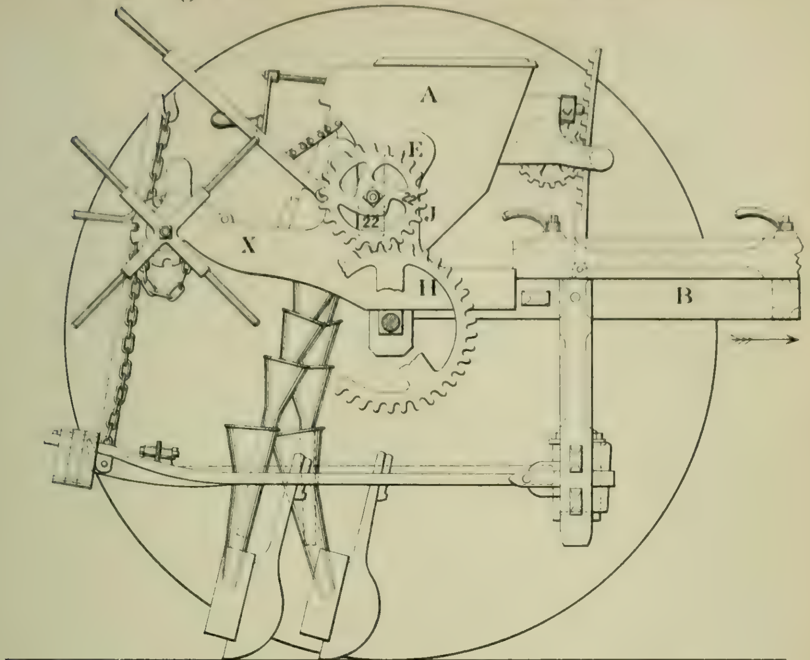
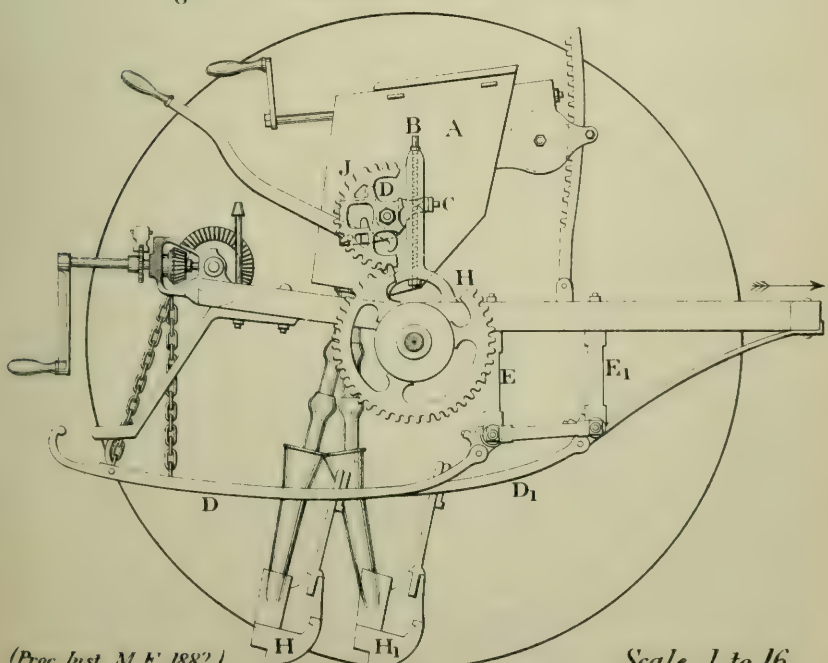


Fig. 24. *Woolnough's Corn-Drill.*



 Scale 1 to 16.

Fig. 26. *American Drill.*

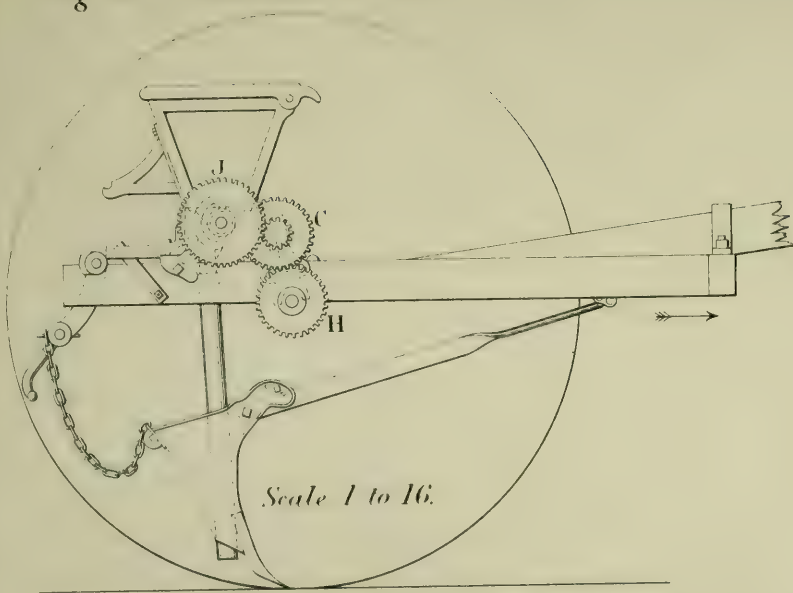
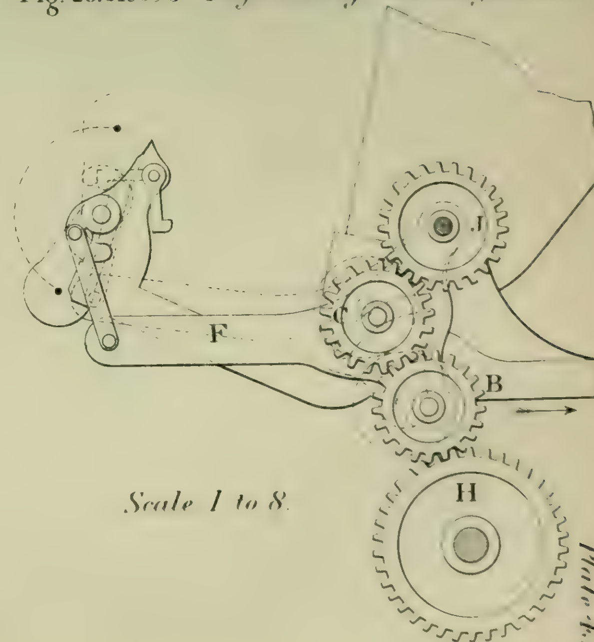


Fig. 25. *Kell's Regulating Arrangement.*

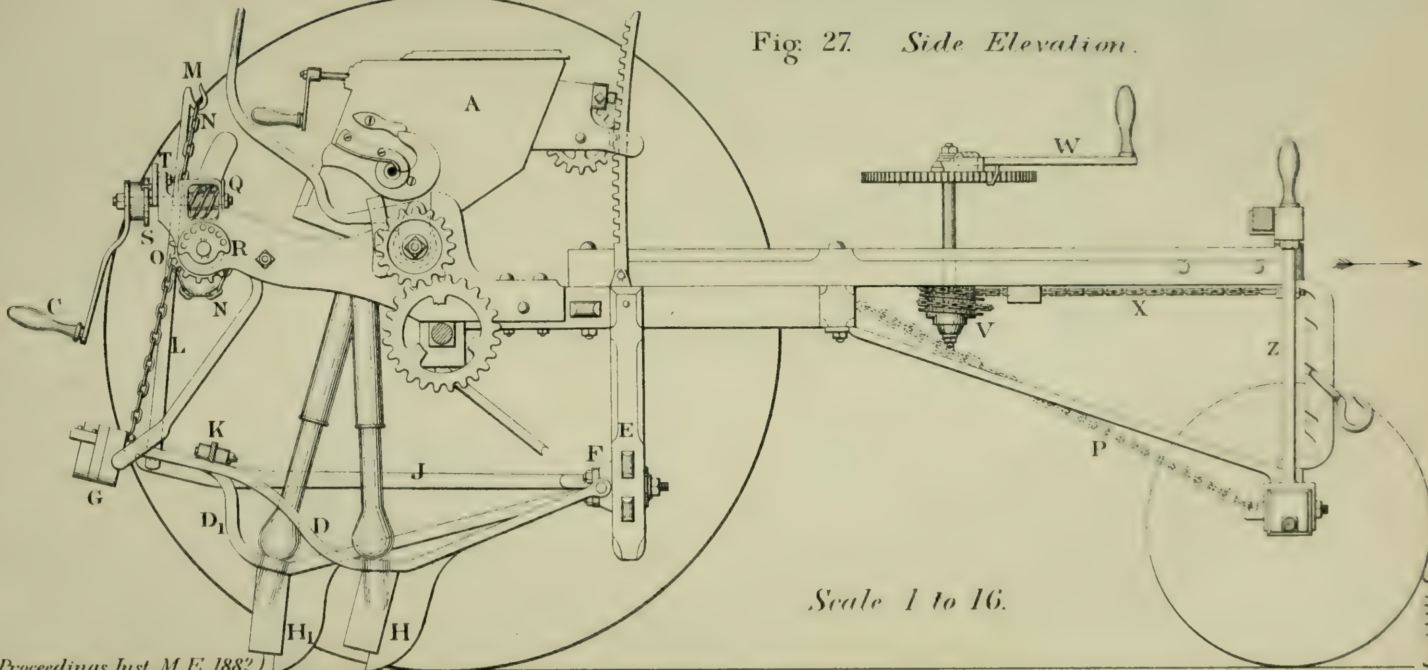


(Proceedings Inst. M. E. 1882.)

SEED-SOWING MACHINERY.

"Nonpareil" Corn-Drill.

Fig. 27. *Side Elevation.*



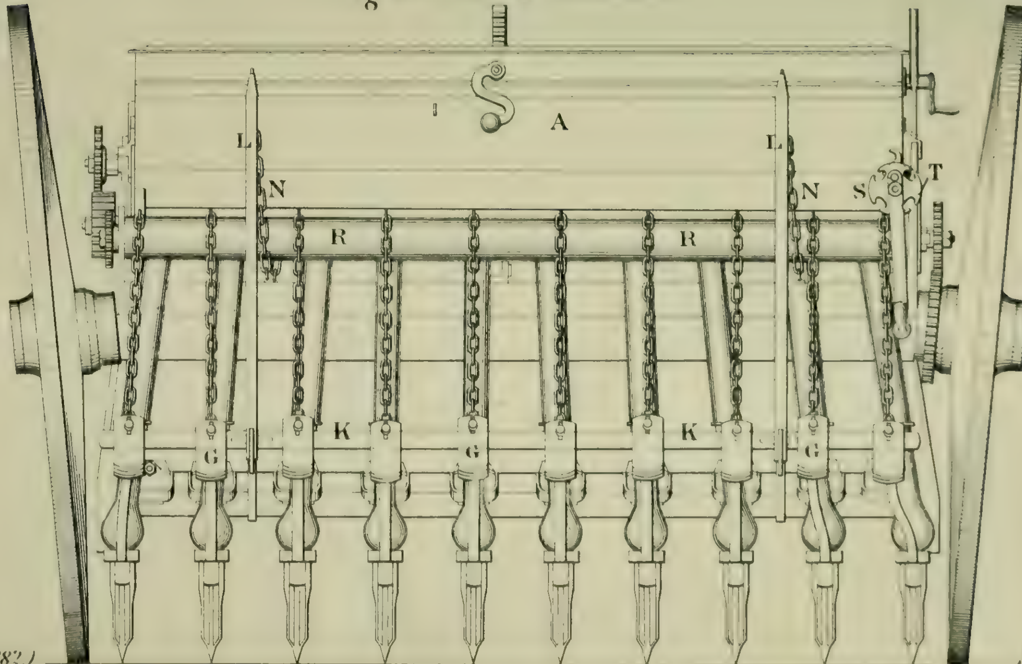
Scale 1 to 16.

Plate 44.

SEED-SOWING MACHINERY.

"Nonpareil" Corn Drill.

Fig. 28. *Back Elevation.*



(Proceedings Inst. M. E. 1882.)

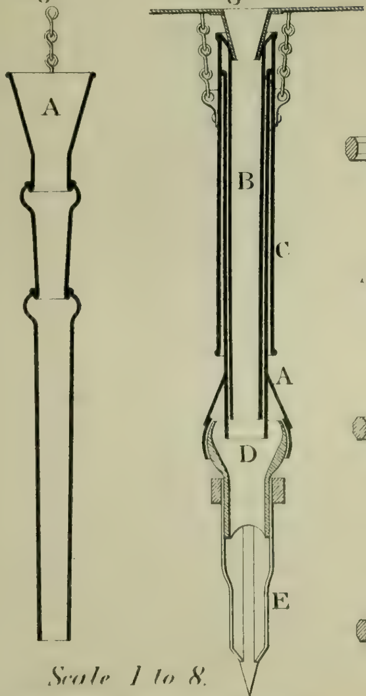
Scale 1 to 16.

Plate 45.

SEED-SOWING MACHINERY.

Conductors.

Fig. 34. Fig. 33.

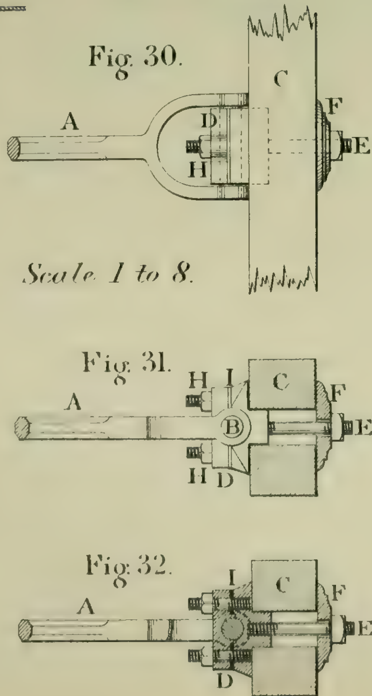


Scale 1 to 8.

(Proceedings Inst. M. E. 1882.)

Lever Joint.

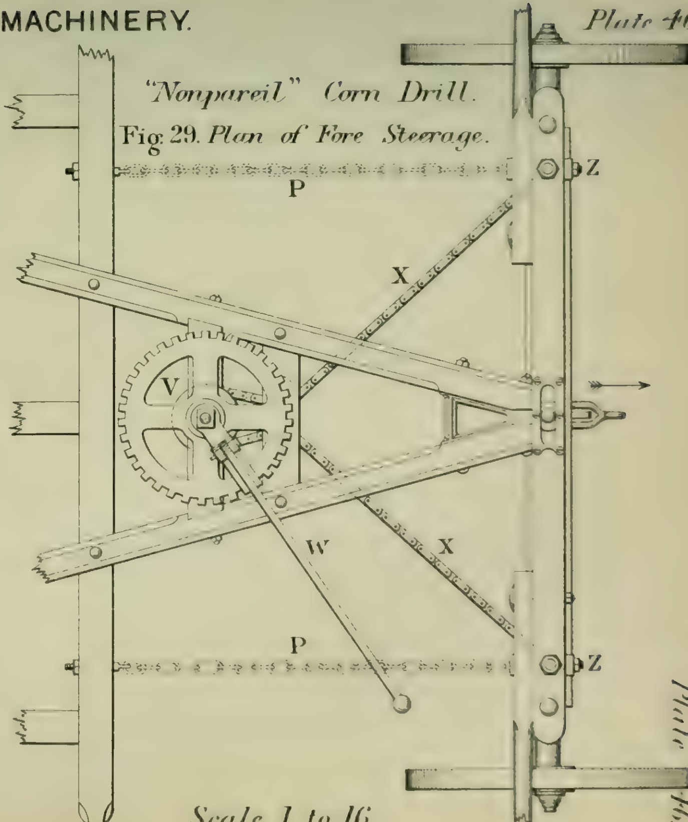
Fig. 30. Fig. 31. Fig. 32.



Scale 1 to 8.

"Nonpareil" Corn Drill.

Fig. 29. Plan of Fore Steerage.



Scale 1 to 16.

Plate 46.

Institution of Mechanical Engineers.

PROCEEDINGS.

August 1882.

The Summer Meeting of the Institution was held at Leeds, commencing on Tuesday, 15th August, 1882, at half-past ten o'clock, a.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The Members were received by the Mayor of Leeds, George Tatham, Esq., in the Civil Court of the Town Hall.

The Mayor said he had much pleasure on behalf of the town in welcoming to Leeds the Institution of Mechanical Engineers. The object of the Institution was of no selfish character: it was not the advantage of individuals which it fostered, but the promotion and advancement of excellence in the arts—a matter of very great importance to all manufacturing communities like their own. When a country had become pre-eminent in arts, and for skill in conducting its affairs, it was very liable to rest in that pre-eminence, and not take sufficient care to keep ahead of the times; and other countries, by the aid of their advantages—such as education, technical schools, and exhibitions of various kinds—were then able to get beyond it in the race. If that were so, it was an additional reason why efforts should be made by such a country to recover its pre-eminence; and the work of the Institution tended generally in that direction.

To his mind the great requirement of the present day was the securing of excellence in whatever work was undertaken. There was too easy a feeling in favour of going on in the old way, instead of securing to themselves all the advantages which they might obtain. Besides the large public improvements which the Institution often brought forward—great and palpable improvements which were

perhaps generally and freely adopted,—there were many small economies of little importance in themselves, but which in the aggregate made all the difference between a profitable and a profitless trade. It was the duty of employers to obtain the best possible appliances for carrying out their work, and then it was the duty of the employed to work those appliances with intelligence, skill, and alacrity, in order that their productions might be the best in quality, quantity, and price. This country would not be able to maintain its supremacy except by the aid of foreign trade; and to secure foreign trade it must produce what it had to sell at as low or a lower rate, quality being considered, than any other country; and he was quite satisfied that if they did their duty—if employers secured the best appliances, and if workmen used those appliances with the skill, industry, and alacrity, which they were able to exercise—they would, in point of quality, quantity, and price, secure a full share of the world's trade. If they succeeded in that, they would increase the demand, augment their own profits, and secure their trade; and the workmen would at the same time secure more employment and better wages. In that way there would be prosperity all round. It was the object of the Institution to promote that result, and in this object it had their hearty wishes for its entire success.

The President said that the Mayor had given the members of the Institution a pleasant welcome to the ancient and thriving borough of Leeds; and in their name he desired to thank him very cordially for the honour and courtesy shown to them. He was sure that they all cordially endorsed the sentiments which had fallen from the Mayor, who had inaugurated what he was confident would be a most successful meeting. The interest and the generosity which had been shown by the large and influential Local Committee, and the exertions made, and the excellent arrangements carried out, by the able Executive Committee, could not fail to produce the success which they all desired.

The Institution had come to Leeds with great expectations. It was on this spot that one of the earliest seeds of mechanical art

fell; it had taken deep root in congenial soil, and being nurtured by strong clever heads and skilful hands, it had grown up and was still growing into a strong tree with many outspreading and vigorous branches. It was here they would meet the descendants and successors of many eminent men in their profession; here too they looked forwards to the pleasure of a free and open intercourse with many of their professional brethren in the district; and here also would be open to their free inspection a large number of interesting works and factories. So much for the professional pleasures that were before them. Then, with regard to creature comforts, they were guests in a Yorkshire town; and whenever a Yorkshireman opened his hand in the way of hospitality, everyone knew what was to be expected. Again he desired to thank the Mayor for the courtesy he had shown, and for the kind reception he had given to the members of the Institution.

The President said, before they began the business of the meeting, he felt sure the members would deem it fit and proper that he should, as their President, and in their name, pay a tribute of respect to two distinguished and honoured late Members of the Council, whose inevitable close of life had fallen upon them since the last summer meeting. In William Menelaus the Institution had lost one whose ripe judgment and experience would have been of great value in leading its affairs at the present time. It was generally known that he had consented to succeed to their late President when his term of office came to a close; but a warning malady, commencing at the time of the Newcastle meeting, had compelled him to give up the idea of accepting the honour and distinction which the members would have been only too proud to confer upon him. And then what should he say of that amiable true friend and adviser of the Institution, Charles P. Stewart? His sterling worth, his keen knowledge and experience, were warmly appreciated and widely known by a large circle of admiring friends and acquaintances. But for an infirmity, which he bore with manliness and patience, the Chair of the Institution would long since have been honoured with the

enrolment of his name, and the Institution would have benefited still more than it had done by his work. To the memory of these two names—Menelaus and Stewart—they paid this tribute of respect.

The Minutes of the previous meeting were then read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and the following candidates had been found to be duly elected :—

MEMBERS.

James Armer, ...	Dartford.
George Frederick Armstrong, . .	Leeds.
Thomas Lake Aveling, ...	Rochester.
Henry Bernouilli Barlow, . . .	Manchester.
John James Barrett, ...	Bombay.
Augustus Jesse Bowie, Jun., . . .	San Francisco.
John Bulmer, ...	Newcastle-on-Tyne.
Edmund Butler, ...	Kirkstall.
John Campbell, ...	Soerabaya, Java.
Hedley Chapman, ...	Newcastle-on-Tyne.
William Wikeley Clayton, . . .	Leeds.
Joseph Coates, ...	Lincoln.
William McDougall Courtney, . .	Dublin.
John Craven, ...	Leeds.
Samuel Denison, ...	Leeds.
Gavin Gemmell Dick, ...	London.
Thomas Graham Elliott, ...	Leeds.
Thomas C. Fawcett, ...	Leeds.
Robert Alexander Forsyth, . . .	Newport, Mon.
Frank Garrett, ...	Leiston.
Richard Garrett, ...	Leiston.
John Willim Hall, ...	Cardiff.
Edward Hayes, ...	Stony Stratford.
Richard Hodson, ...	London.

Samuel Johnson, ...	Rochdale.
Thomas Kirkwood, ...	Hong Kong.
Marcos Mañé, ...	London.
Robert Masefield, ...	London.
Richard St. George Moore, . . .	Hull.
Thorsten Nordenfelt, ...	London.
Vernon Petherick, ...	Nottingham.
Christopher Edward Phipps, . . .	Madras.
Thomas Purvis Reay, ...	Leeds.
Vincent Rhodes, ...	Grantham.
Alfred William Seabrooke, . . .	Bombay.
Norman Selfe, ...	Sydney.
John Harwood Simpson, ...	Portskewett.
Walter Parker Smith, ...	London.
James Josiah Smyth, ...	Peasenhall.
John Sturgeon, ...	London.
William Swinburne, ...	Newcastle-on-Tyne.
John O'Brien Tandy, ...	Crewe.
Robert Henry Taylor, ...	Gosport.
Thomas Albert Oakes Taylor, . .	Leeds.
William Thow, ...	Adelaide.
William Wakefield, ...	Dublin.
Henry Burnett Watson, ...	Newcastle-on-Tyne.
Charles Dickinson West, ...	Tokio, Japan.
Alfred Edward White, ...	Hull.
Alexander Basil Wilson, ...	Belfast.
John Frederick Wolff, ...	Gloucester.

ASSOCIATE.

John Henry Sokell, ...	Leeds.

GRADUATES.

Samuel Richardson Blundstone, . .	Gloucester.
Warine Ben Hay Martindale, . .	Newcastle-on-Tyne.
Saxton William Armstrong Noble, .	Newcastle-on-Tyne.

The President then delivered his annual Address.

Mr. E. Windsor Richards proposed a hearty vote of thanks to the President for his Address, which was seconded by Mr. Edward Williams, and carried by acclamation.

The following paper was then read :—

On the History of Engineering in Leeds; by Mr. A. H. Meysey-Thompson, of Leeds.

The President said that, as this paper was a historical one, it was not open to discussion. It only remained for him to call upon the members to give a hearty vote of thanks to the author for his admirable paper.

The vote of thanks was carried by acclamation.

The following paper was then read and discussed :—

On the Working of Blast-Furnaces of Large Size, at High Temperatures of Blast, with special reference to the Position of the Tuyeres; by Mr. Charles Cochrane, of Stourbridge, Vice-President.

At 1 p.m. the discussion was adjourned till the following day.

The Adjourned Meeting of the Institution was held in the Civil Court, Town Hall, Leeds, on Wednesday, 16th August, 1882, at half-past ten o'clock, a.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The discussion upon Mr. Charles Cochrane's paper on Blast-Furnace Working was resumed, and concluded.

On the motion of the President, a vote of thanks was unanimously passed to Mr. Cochrane for his paper.

The following paper was then read and discussed :—

On Mining Machinery; by Mr. Henry Davey, of Leeds.

On the motion of the President, a vote of thanks was unanimously passed to Mr. Davey for his paper.

The following paper was then read and discussed :—

On a Single-Lever Testing Machine; by Mr. J. Hartley Wicksteed, of Leeds.

At 1 p.m. the discussion was adjourned till the following day.

The Adjourned Meeting of the Institution was held in the Civil Court, Town Hall, Leeds, on Thursday, 17th August, 1882, at half-past ten o'clock, a.m.; Percy G. B. Westmacott, Esq., President, in the chair.

The discussion upon Mr. J. Hartley Wicksteed's paper on a Single-Lever Testing Machine was resumed, and concluded.

On the motion of the President, a vote of thanks was unanimously passed to Mr. Wicksteed for his paper.

The following paper was then read and discussed :—

On Governing Engines by regulating the Expansion; by Mr. Wilson Hartnell, of Leeds.

On the motion of the President, a vote of thanks was unanimously passed to Mr. Hartnell for his paper.

The President proposed the following Votes of Thanks, which were carried by acclamation:—

To the Mayor and Corporation of Leeds for their reception of the Members, and the facilities given in connection with the use of the Town Hall during the Meeting.

To the Local Committee of Leeds, the Local Committee of Hull, and the other gentlemen in the district, who have so hospitably and liberally entertained the Members during the Meeting.

To the Firms in Leeds and the neighbourhood, and in Bradford and Hull, who have thrown open their Works to the visit of the Members.

To the Directors of the North Eastern Railway and of the Midland Railway, for their kindness in providing special free trains for the Excursions.

To the Managers of the Bradford Textile Exhibition, the Philosophical Hall, Leeds, the Royal Exchange, Leeds, and the Mechanics' and other Institutions, for the facilities afforded to the Members during their visit.

To the Executive Committee, especially the Chairman, Mr. Kitson, the Treasurer, Mr. Joseph Craven, and the Honorary Local Secretaries, Mr. John Barber, Mr. J. Hartley Wicksteed, and Mr. Frank H. Pearson, for their active and valuable services in maturing all the arrangements for ensuring the success of the Meeting.

The Meeting then terminated.

PRESIDENT'S ADDRESS.

Gentlemen,

It has not always been the custom of your President to deliver an address; and I am free to confess I should have preferred to edge my way quietly through the breach of this observance, but that I hold with those who consider it the duty and privilege of a President to add his contribution to the Proceedings of the Institution.

We are indebted to Members for placing on record, with much pains and care, the practical results of their experience, inventions, experiments, and work, in all the varied branches of our ever-enlarging profession; and the Proceedings of our Institution are thereby becoming of great value as a means of instruction and reference.

It is desirable however, in order to fill up the measure of this work, that there should be added, from time to time, a general survey of progress—some stock-taking, in fact, of work done—some guidance, help, or advice to younger members of the profession—some forecast of the direction in which investigations or improvements or inventions should be pressed—some expression of thought, or reflection, to raise the mind to the higher attributes and duties of our profession: and it is to the Chair of our Institution that we may very fairly look for the accomplishment of this portion of the work.

About this time last year we received from our Past-President, Mr. Cowper, a most admirable and concise summary of the recent progress of Engineering and scientific inventions; and shortly afterwards, at the meeting of the British Association, another of our Past-Presidents, Sir Frederick Bramwell, shook down with all his power and generous energy the ripe fruits of his knowledge and

experience in engineering and scientific matters during the progress of the past half-century.

I shall not attempt to traverse the same ground. Even if I had the power or experience to do so, it must be confessed that this last year has been unusually barren in mechanical inventions; but at the same time, many scientific and mechanical appliances are being projected and pressed forwards into use, for the benefit and, let us hope, for the peace of mankind.

Reflecting then upon the results of the great and rapid progress in practical science and art that has taken place of late years, there is, it appears to me, a point of significant interest to Engineers, and it is this: that the nation or community which applies its inventive faculties, its powers of adaptation and construction, to the moving of materials for useful purposes with the least amount of manual labour and waste—in a word, which extends and cheapens transport by land and by water—is in the van of all real work, substantial progress, wealth, and civilisation.

It requires no statistics to prove this—no toy calculations, having for their base some popular formulæ such as the measure of a belt round the earth, or the distance from earth to moon, to call forth comparisons. We have but to glance back at man in his savage state, living with earth's latent riches around him, and yet incapable of moving these rich materials for his benefit, without the guidance of some higher intellectual and cultivated power. We have but to contemplate the marvellous and gigantic structures of the East, which were erected, at an enormous waste of manual power, for no good or useful purpose to mankind, and thus stand as monuments of man's pride and self-glorification. There was no power of real and beneficent progress in these—no real work.

How do we in this country stand in this respect? We may reverse the medal; we have availed ourselves of the natural resources of our land; we have made progress and done good work: but, in all humility we must own, the results of our work and progress have been greatly tarnished and impeded by the savage waste and selfish spoliation of the good things we have moved and lived upon for our benefit. We may pride and plume ourselves upon the vast strides

which science, art, and engineering have made in our own time; but posterity will assuredly lay its finger upon the great blot of *Waste*, and may stigmatise our age as the *Black Age*, which has spoilt, by careless, unnecessary, and selfish emissions of smoke and noxious gases, many a noble town and many a lovely spot on earth.

The smoke nuisance is altogether inexcusable, and cannot be too severely dealt with. Science and art have practically overcome it; and experience enables many, like myself, to assert that money can be profitably laid out and yield good interest in the abatement of this unpardonable nuisance.

Then with regard to waste, much ingenuity and skill have certainly been displayed, and much work has already been done, to lessen this evil; and the records of our Institution will bear witness that many of our members have striven and succeeded well in their efforts to remove this stigma from our age. I would urge upon the younger members of our profession to study this question profoundly, and as if the whole of their success in life depended upon it; and never to undertake the smallest piece of work without wrapping it round with economy. Those who carry out this advice will assuredly succeed.

May I not go so far as to say that no really good and useful invention is ever wasted or completely thrown aside, even though it may be superseded, permanently or for a time, by some other invention? This to my mind is an important reflection, one extending far beyond professional views; for its realisation would greatly assist in alleviating those injurious alarms, which are often felt when some new and striking invention bursts upon the world.

To illustrate this, let us take for an example the present prominent question of lighting. We may go back to the period when the diffusion of light depended upon oil; after a time candles were introduced; then came the great and important invention of gas; and now, at the present time, electricity is being brought into use. Well, what do we find in all these competing agents, each good and useful in its way? We find that not any one of these sources of light exercises a monopoly. Candles have not interfered with the use and progress of the oil lamp; gas has not snuffed out

candles, or stopped the flow of oil for lighting purposes; and I do not hold with those who believe that electricity will totally eclipse gas.

Or again, let us take for example the means of transport across the land. Rough and miry tracks were first of all made for cattle traffic; they were then improved for horse and cart traffic, and were still further developed by Macadam for swift-running carriage traffic. Then there were canals; and lastly railways, which owe their origin to the very simple idea of confining the run of vehicles to a defined line of hard rails. This happy idea laid the foundation of that great development of mechanical traffic which has assisted to open out and spread abroad the riches of the world, and has given to science and mechanical art a wide field of labour.

Thus a new system of transport may become the main artery through which material is moved and spread over the land; but the increased facility which such an improved system of conveyance gives, and the enlargement of trade which results therefrom, require increased feeding powers; and thus the system which one day is the principal artery forms another day the side arteries. And yet the amount of work done by the old system is not necessarily diminished; on the contrary it may be very materially increased by the impetus of improvement in some other direction, and by the benefits of competition.

Now it may at first sight seem singular that railways, lessening as they have done to an enormous extent the cost of land carriage in comparison with cart traffic, have neither done away with horses and carts, nor drained canals of their freights. On the contrary, there is more horse and cart traffic than ever: indeed railway companies are among the largest proprietors of horses, and the most extensive carters in the country. The formation of macadamised roads progresses even now, and has enlisted the skill of engineers and mechanics for their cheaper construction and better maintenance. Canals, though at times severely opposed by railways, still hold their own, and carry more traffic than they did in the days when they had all their own way; and canal engineers have been as forward in availing themselves of modern appliances, and have shown

as much boldness in designs for quickening and cheapening the transit of materials, as any other labourers in the same field.

Let me here, in passing, refer to a local piece of engineering for the coaling of vessels.

On the Aire and Calder canal, which terminates in the docks at Goole, may be seen snake-like coal-trains propelled by steam, gliding quietly along the course of the canal. These trains are composed of square-shaped wrought-iron barges, vertebrated into one another, and furnished with a cut-water bow-piece in front, and with a steam propelling compartment abaft. The train of boats is steered by two ropes, strung along the sides of the barges from end to end, one end of each rope being fastened to the bow, and the other end passing round drums fixed on board the engine compartment. These drums are worked by steam reciprocating gear. On entering the docks the trains are disjointed; and each barge, containing about 36 tons of coal, is brought under a hydraulic hoist, which lifts the barge bodily out of the water, and upsets its contents directly into the vessel. Thus the barges are filled from the pit's mouth by gravity, and by gravity are again emptied of their contents—a truly complete labour-saving system.

May not this system, which is being further developed for fly-boats of 130 tons weight, be the precursor of times when ocean-going steamers may, without loss of time, on arriving in port, be lifted bodily out of the water, and then scuttled of their contents right and left into warehouses, at a rate and with a saving of labour which would far exceed anything hitherto attempted? At the same time this would give the owner an opportunity of examining the hull of his vessel, and of cleaning and repairing it if need be. There is nothing, to my mind, impracticable or extravagant in the forecast of such a development for hydraulic ship-hoists and graving docks. It may at first sight appear that there would be an extravagant loss of power in lifting the ship itself bodily out of the water; but it can be proved that the dead weight which is lifted in discharging cargoes by means of buckets—as in the case of coal, ore, grain, &c.—is about as much as the dead weight of the ship itself.

Whether it be in some such direction that we are to look for a

mode of moving materials quickly from and into a vessel—or whether to some improved system of dock or quay arrangement, whereby a vessel entering a port can at once be handled on both sides for traffic purposes (by some such plan, for instance, as a combination of fixed and floating jetties, amply provided with mechanical appliances for lifting and moving goods)—it is certain that any system which will materially quicken or cheapen the discharging and loading of steamers, thereby reducing the still life of costly vessels in port, will effect an economy that will tell to advantage on all the interests, direct and distant, which can be brought to bear upon the ocean-going traffic of this country.

In conjunction with the direct advantages which the rapid handling of goods gives to vessels, there is another interest which shares also directly the benefit of quick despatch, namely that of the dock companies themselves. It is clear that the greater the amount of tonnage which can be brought to the quays of a dock, the greater will be the return upon the outlay of capital in the construction of such works. This result is accomplished by the adoption of an abundant supply of quick-working mechanical appliances, not only for discharging and loading, but for working the dock gates, bridges, capstans, warehouses, and railways. Now the economy resulting from a concentration of work to the fullest extent upon a limited area has not always been properly recognised by dock companies. It has frequently happened—but more so abroad than on our own coast—that, where pressure due to an increase of trade has come upon a dock, it has been met by enlarging the dock area and lengthening the quay space at a great cost, instead of first making the best use of mechanical arrangements for quickening the discharging of vessels, and for the movement of goods to and from the quay. The late Mr. T. W. Collett informed me that, after the old St. Katharine dock of London had been furnished with a complete system of hydraulic machinery, it was able to turn out three times the amount of trade that could be done in that same area of dock space before.

Alluding to shipping and the moving of material, there is perhaps no work that has given more life to our country, or

has done more to increase our wealth and prosperity, than the improvement of rivers, and the formation of docks. Without a ready outlet for our minerals and manufactured goods through the water gates of our coast, the development of our trade and railways would never have taken place. Any engineering work therefore that promotes and improves our shipping, and facilitates and cheapens the cost of transit, acts directly upon the prosperity of our country.

The considerations of economy, which are affected by the concentration of effective work upon a defined area of dock water or quay space, apply of course with equal force to railway goods-sheds and warehouses; and in this respect we shall find, I believe, that in this country we are greatly in advance of the Continent and America. In travelling through those countries I have been struck with the comparatively large areas over which, as a rule, goods-sheds &c. are spread; and still more so with the absence or incompleteness of mechanical appliances for saving manual and horse labour in railway yards and warehouses.

It is not within the compass of an address to follow, through all the phases of our profession and art, the theme of the moving of materials, nor to pursue and dwell upon the contrivances for cheapening land and water traffic. These might well form the subject for a volume. I will therefore now conclude by remarking that one of the duties which the acquirement of wealth and prosperity brings upon our nation is the duty of their defence; and it behoves us never to neglect the taking of sufficient and constantly increasing precautions to protect our own trade, and to provide ourselves with every means for moving war materials by land and by water in times of difficulty, with the least amount of manual labour. In this respect countries are like those individual manufacturers who, desiring to press forwards and to be in the front rank, exercise their powers and expend capital again and again upon various appliances, in endeavouring to strengthen and to improve their work.

ON THE HISTORY OF ENGINEERING IN LEEDS.

BY MR. A. H. MEYSEY-THOMPSON, OF LEEDS.

The connection of Leeds with Engineering dates from a very early period.

As early as the commencement of the 16th century we find Bishop Tonstall asserting, at the time of Henry VIII.'s visit to Yorkshire, that this district was the richest he found in all his travels through Europe ; there being within ten miles of Hazlewood, *inter alia*, "120 rivers and brooks, whereof 5 be navigable ; 76 water mills ; 25 coal mines which yield abundance of fuel for the whole country ; 3 forges for the making of iron, &c."

Leeds however must have given employment to the civil engineer long previous to this date ; for, from a charter granted to the burgesses of Leeds at the commencement of the 13th century, it is evident that they exported by water as well as by land. About the time of Charles I., an Act was obtained for rendering navigable the rivers Aire and Calder ; according to Thoresby, "the first undertaking of the kind in the kingdom, and, after the great canal of Languedoc, in Europe, by which Leeds acquired many of the advantages of a port, while it retained the security of an inland town."

Thoresby also informs us that, in the year 1695, "the ingenious Mr. George Soroceld, the great English engineer," constructed a water engine, by means of which river water was conveyed through lead pipes to the several parts of the town ; and from the same writer we learn that in the year 1714 a native of the town had invented a machine in which he turned "large and strong pieces of iron and steel, useful in all strong machines and movements, as mills for plate, tobacco mills, malt mills, spindles for corn mills, &c. Jacks are also made after a new and curious method, the wheels and

axes and all the moving parts (which formerly and now by most are filed) being all turned down to exactness, and the teeth cut."

Mechanical engineering however appears to have made but little progress prior to the commencement of the present century. The necessary machinery for the various mills in the district, whether driven by wind or water-power, was of a very simple character; and the appliances for colliery working, or for the smelting and working of iron, were of a very primitive description.

It was about a hundred years ago that improvements in the steam engine gave an impetus to mechanical engineering throughout the country; and the genius of Matthew Murray soon enabled the Leeds district to take a prominent place in this industry.

Murray commenced his career in Leeds at the flax mill of John Marshall, about the year 1789, at a time when the manufacture of flax by machinery was just commencing; and by the improvements which he introduced into the machinery, he gave to the flax trade of the district a start which it has never lost. Perhaps his most important inventions in this class of machinery were the hackling machine (which procured him the prize of the Gold Medal of the Society of Arts), and his machine for wet flax spinning by means of sponge weights, which proved of the greatest practical value.

The great advantages gained by the trade of the district from these inventions were still further enhanced by the inventions of John King Wesley, which were of the first importance. Probably his most valuable invention was the screw gill, introduced in 1833 in conjunction with the late Mr. S. Lawson, which was at once adopted, and with very slight modifications still continues to be used in the preparation of flax, hemp, jute, silk, and worsted. Wesley also invented the sliver-roving, the D gill, and other machines.

Murray continued in Messrs. Marshall's service up to the year 1795; when, realising the great want there existed for trained mechanics and organised works for the better manufacture of improved flax machinery, he secured the co-operation of Fenton and Wood, and started—in the works known as the Round Foundry, and now in the occupation of Messrs. Smith Beacock & Tannett—the

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well-known firm of Fenton Murray & Wood, afterwards Fenton Murray & Jackson.

Not only did Murray manufacture flax machines, but he also turned his attention to engines for driving them; and so successful were the latter, that engine building soon became a large branch of his manufacture.

Two engines of his make, one of 50, the other of 16 H.P., are still driving machinery at Messrs. Tetley Tatham and Walkers, Water Hall Mills, Holbeck. For one of his engines, sent to Russia, he received a gold medal from the Emperor. Whether this medal was the only payment received for the engine, history does not state. The invention of the double cylinder was also due to Murray.

At the commencement of the present century all the engines for flax spinning were of the beam type. The long D slide-valve, usually employed in those engines, was, according to Smiles, either invented or greatly improved by Murray; and it was probably owing to the difficulty experienced in getting the two surfaces of the valve perfectly true to one another that he was led, if not to the invention, at all events to the development of the planing machine. So rapidly did his business progress in the North of England, that James Watt found him a formidable rival—so formidable indeed that the firm of Boulton and Watt bought up the land round his works to prevent their extension.

In 1812, in conjunction with Blenkinsop, Murray brought out what was undoubtedly the first locomotive engine ever successfully employed for commercial purposes. It was constructed for the conveyance of coal from the Middleton Colliery to Leeds, a distance of about 3½ miles; and was capable of dragging thirty loaded coal wagons at a speed of between 3 and 4 miles an hour. Four of these engines were made by Fenton Murray and Co.; the "Salamanca" and "Prince Regent" were set to work in August 1812, and the "Lord Wellington" and "Marquis Wellington" in 1813; they continued to run for about twenty years on the above railway. Fig. 1, Plate 47, represents this type of engine so clearly that it is needless to describe it; but any members who have seen Stephenson's earliest engine, set to work at Killingworth two years

later, cannot fail to be struck with the close resemblance between the two: the main points of difference being in the driving wheels and the roadway, rather than in the engine itself. Figs. 2 and 3, Plate 48, represent the Killingworth engine, and are copied from Nicholas Wood's "Practical Treatise on Railroads."

Murray's works were the school in which numbers of engineers of note in the early part of the present century were educated, many of whom started works in Leeds and elsewhere. The author proposes to indicate briefly the progress which has been made since Murray's death, which occurred in 1826. For this purpose a chart, Fig. 4, Plate 48, has been compiled, to indicate at a glance the dates at which the various trades commenced in Leeds.

In the year 1826 Mechanical Engineering in Leeds comprised—1. Textile machinery; 2. Locomotives; 3. Fixed engines;—all of which were then made solely by the firm of Fenton Murray & Wood, at that time the only firm of mechanical engineers in Leeds. Between 1795 and 1826 this firm employed about 200 men each year; whereas the number now employed in the mechanical engineering shops of Leeds is about 12,000.

As time went on, the large textile manufacturers began to require tools for the repairing of their machinery; and about the year 1837 the manufacture of such tools became a distinct branch of trade, two firms starting at that time solely for this purpose. The tools required for machine repairing were tools suitable for general engineering manufacture, such as lathes and planing machines; and it is interesting to observe how little these two machines, which are still the leading tools of engineering shops, have been altered from their original forms.

Between the years 1830 and 1840 the railway system had become established, and so rapid was its development that a large and increasing demand for locomotives quickly came into existence. In the year 1837 a steamer actually crossed the Atlantic; and shortly after, a new manufacture, viz. that of the marine engine, was initiated. This revolution in the mode of transit by land and water created a new branch of the tool trade, owing to the fact that the

manufacture of locomotive and marine engines required special machinery, of larger dimensions than had previously been used or found necessary for other purposes. The tool makers in Leeds were not slow in meeting this fresh demand on their resources; and the tool trade grew rapidly until about the year 1852, when it received a further impulse from the change at that time made in shipbuilding by the substitution of iron for wood.

This new industry created a demand for still heavier tools, not only for the building of ships, but also indirectly for the preparation and manufacture of the iron in the iron works. So rapid was the growth of this branch of manufacture that it is not surprising to find that by the year 1866 the tool trade of Leeds had grown to very large proportions, employing about 8000 men. At the present time the trade is one of the most important industries of the town. In Leeds some of the heaviest and best tools are made, and, as will be seen further on, some of the most ingenious tools for special manufactures.

About the year 1854 a new branch of machine making was introduced, owing to the outbreak of the Crimean War. Our arsenals at that time were without the machinery or other means requisite to supply the demand for war material. Leeds tool-makers came to the rescue, and largely supplied that want by producing machines for the manufacture of rifles, fuses, rockets, gun carriages, powder barrels, and cases. The variety and extent of these machines may be judged from the facts given by Mr. Greenwood, in his paper read before the Institution in 1868 (Proceedings 1868, p. 105). He there describes the twenty-one machines required in the manufacture of a cartridge, and observes: "The several operations required are performed by the machines at the very rapid rates of from 3,000 to 150,000 per day, as named for each machine."

In addition to the manufacture of what is commonly termed Small-arm machinery, Leeds has also sent out a great number of very powerful tools for turning, boring, and rifling heavy ordnance. Since the adoption of the Armstrong system, enabling guns to be built up to almost any size by means of wrought-iron coils, the weight of ordnance has been constantly increasing; and the machines which a few years previous were amply large enough have had to be

replaced by still heavier ones. Within the last few years, Leeds has sent out tools for turning, boring, rifling, and slotting the 100-ton guns now in service.

Locomotive engine building has for the last fifty years held a prominent position in Leeds—a position in great measure due to the enterprise and energy of Mr. Kitson, whose labours in this direction have continued nearly half a century. Of late it has received a further development by the introduction of tramway engines. Another branch of this manufacture, that of agricultural machinery, was commenced in 1860 with the introduction of the steam plough, and is now one of the most important industries of the town.

Fixed engines, up to the year 1860, consisted chiefly of small pumping and rotative engines for driving machinery. Since that time however, the great improvements in steel-making plant, the introduction of the compound pumping engine, and the extra facilities required at our large docks and railway stations for loading and unloading goods, have given rise to a large and increasing demand for pumping and hydraulic machinery of all kinds; whilst the improvements which are made almost daily in electric lighting promise a large field for the enterprise of those engineers who are now endeavouring to introduce an efficient motor, to be worked either by gas or by steam.

The author has thus tried as far as possible to point out the directions in which engineering has developed in Leeds, and to indicate the periods at which the various manufactures became regular branches of industry: though undoubtedly in many cases individual machines were made prior to the dates here given.

In addition to the above industries there are several others in which machinery is largely employed; and as they are of comparatively recent date, and to a certain extent peculiar to Leeds, a short notice of them may be of interest to the members. The trades are as follows:—

1. Machine-made clothing;
2. „ „ hats and caps;
3. „ „ boots and shoes;
4. „ „ nails.

1. Although the most ancient of all handicrafts—the only one in fact which our first parents practised, so far as we have any record,—the art of tailoring has not, so far as the author is aware, received any assistance from mechanical appliances until within recent years. The sewing machine, ever since its invention, has no doubt been employed to a limited extent by tailors; but it was not till the year 1857 that machinery was introduced to any extent into the manufacture of what is commonly called "ready-made clothing" in Leeds. From comparatively humble beginnings, the manufacture has increased so rapidly that at the present time from three to four million garments are annually made in Leeds; and the machines have arrived at such perfection, that few processes now remain to be done by hand.

The first stage of the manufacture is to cut out the cloth, for which purpose a machine is employed similar in construction to a band saw, but having a knife edge. Some twenty-five double pieces of cloth, laid on one another, are cut at a time; thus enabling the several parts of twenty-five suits to be cut out more quickly and more accurately than one could have been by hand. The parts thus cut out are then united by sewing machines, running at from 700 to 800 stitches per minute, normal speed; though some travel as fast as 2000 stitches. The seams have next to be ironed; and as the old system of heating irons in a fire has been found both troublesome and costly, metal cases have been adopted, inside each of which is a Bunsen burner with upwards of 100 jets of gas, the case itself being fixed at the end of a radial arm provided with elbow joints. The necessary 250 lbs. pressure for the ironing is applied by the foot of the attendant pressing on a treadle.

To such an extent is the subdivision of labour carried, that each suit of clothes passes through the hands of from twenty-five to thirty persons. The several processes of cutting out, sewing together, binding, braiding, putting in sleeves, sewing on buttons, making button-holes, and ironing, are all done by machinery. The effect of this system has been to cheapen the cost to a remarkable degree; so much so that a suit of clothes for an adult can be bought at 13*s.*, and for a child at only 2*s.* 9*d.* Power was applied to the machinery

about seven years ago, and it has been found that 1 HP. is sufficient to drive from 20 to 25 machines.

2. A kindred industry, the hat and cap trade, is rapidly assuming large proportions; the machinery employed is much the same as that for the machine-made clothing, and the turn-out of hats and caps per week is about 70,000 dozen.

The total number of hands employed in these two industries in Leeds is estimated to be between 6000 and 7000: of these nearly 5000 are women, whose wages range from 12*s.* to 30*s.* per week.

3. The manufacture of boots and shoes by machinery is also becoming an important industry. It commenced about the same time as the machine-made clothing trade, with a few simple machines, but has grown rapidly, and now gives employment to nearly 5000 hands. The whole of the leather, with the exception of the "uppers," is stamped out by a machine. Very powerful sewing machines unite the parts thus cut out; whilst the "lasting machine" and "finishing machine," recently perfected, have enabled manual labour to be still further dispensed with.

Each boot passes through the hands of from six to twelve persons, and so rapidly can the different processes be performed that a boot can now be turned out complete in about half-an-hour. From one to two million pairs of boots are annually produced by the above processes in Leeds, and so cheap have they become that a pair of strong workman's boots can be bought retail for 6*s.*

4. The manufacture of cut nails has made most rapid strides of late years. Formerly nails were made in presses by manual power. In 1819 steam was first applied in Leeds to this manufacture by Messrs. Roberts, who cut a ton a week, which was then regarded as a large quantity. Since that time the machines have been wonderfully improved. A nail is now cut, headed, and pointed at one stroke; and by a recent improvement a self-acting feed is provided, thus further diminishing manual labour very considerably. In the year 1858 Mr. Kitson, in a paper read before the British Association, estimated the number of hands employed to be 188, of whom 100 were women; and the annual weight of nails made to be 3452 tons. At the present time the annual make of nails

is about 15,000 tons, employing nearly 600 hands, of whom about two-thirds are women.

The iron trade is probably the oldest of all the Leeds industries. Large beds of scoriæ, sometimes penetrated by the trunks of large trees of great age, which must have grown up through them, are to be seen in the neighbourhood.

From the fact of a great number of beds of scoriæ (some yielding Roman coins) having been found close to the old Roman town near Adel, joined to the knowledge that those people were extensive iron-makers, it has been inferred that these are the remains of their workings. Many of these beds of scoriæ are found near the *tops* of the hills, no doubt in order to obtain a natural blast. The site of the furnaces was constantly changed, for the purpose of procuring a supply of wood for fuel as near the furnace as possible. These old iron-workers on the hill tops have left us additional records of themselves in the names of places, *e.g.* Kirkby-Overblow, which was originally called Kirkby Ore Blowers.

The next step in the history of iron-making was the adoption of an artificial blast; and the streams in the neighbourhood afforded an easily applied power for driving the blowing apparatus. The Kirkstall Forge, which is believed by antiquarians to have been started as an ironworks by the monks about the time of the founding of the Abbey in 1152, had evidently a peculiarly eligible site prior to the introduction of steam: being in close proximity to deposits of iron, with an ample supply of timber in the neighbourhood for fuel, while the head of water afforded by the river Aire and adjacent streams gave the power for driving the tilt hammers and procuring a blast.

The inventions of Watt, following closely upon the practical application of pit-coal as fuel for iron-making, rendered the iron-maker independent of hydraulic power; and towards the end of the last century the steam engine supplied the necessary blast to iron furnaces. The Bowling Company, who commenced in 1780, were among the first to profit by these discoveries, and were followed shortly after by the Lowmoor Company. Both these works originally made cast-iron only; but in 1805 the Lowmoor Company commenced

puddling, and boiler plates were made very soon after. That the size of their mills did not increase very rapidly may be inferred from the fact that in 1839 the largest plate which could be rolled in one heat was 9 ft. by 3 ft. by $\frac{3}{8}$ in. In 1856 the width of the plates had only increased to 3 ft. 6 in.; whereas at the present time the largest plate that has been turned out is 10 ft. in width.

There are six works established for the manufacture of what is generally known as Best Yorkshire iron, which is obtained from an ironstone found in the lower coal measures and commonly known as argillaceous carbonate. The total amount of this ore raised in 1881 was about 160,000 tons, all of which was consumed by these six works. The excellence of the pig-iron produced is also due partly to the fuel. What is known as Better-Bed coal is exclusively used for the coke employed in smelting, its remarkable freedom from sulphur and phosphorus making it especially suitable for smelting purposes. The superior quality of the manufactured iron is due not only to the purity of the pig, but also to the extreme care exercised in all stages of the manufacture; the fact of its commanding the highest price in the market being sufficient proof of its excellence.

The author would direct the attention of the members to an open-top atmospheric engine still working at the Lowmoor works for supplying the blast. This engine, as its name-plate testifies, was put down in 1791 by "Emmetts Founderers," of Birkenshaw. It has a steam cylinder 4 ft. 10 in. diameter, with a 7 ft. stroke, and was originally constructed to work with a steam pressure of 5 lbs. per sq. in. A parallel-motion and piston-rod have been substituted for the chain which was originally fastened to the curved end of the beam for raising the piston; and it now works with a steam pressure of 28 lbs.

As before stated, we have it on Bishop Tonstall's authority that in the 16th century there were 25 collieries in the Leeds district. There are now in the West Riding 471 collieries, giving employment to over 60,000 men. The output of coal in 1881 was upwards of 18 million tons, of which about 1 million tons was exported from Goole and Hull, and about 13 million tons went by railway and canal.

In Fig. 5, Plate 49, is given a map of the coal and ironstone district of Leeds, showing the outcrop of the Better-Bed coal &c., and the position of the various ironworks. A section of the strata sunk through is also given in Fig. 6, Plate 50. For this information the author is indebted to the kind assistance of Mr. Rowland Childe, of Wakefield. The coal measures are remarkably rich. Of the two beds of coal chiefly worked, the upper, known as Lowmoor Black Bed, is generally accompanied by the famous Lowmoor ironstone. The ironstone lies in a carbonaceous shale, partly in thin layers and partly in nodules. The layers are in the higher part of the shale. The clay beneath the lower or Better-Bed coal is of excellent quality, and supplies several very large works in the neighbourhood with material for making fire-bricks, tubes, terra-cotta work, gas retorts, and other articles for which refractory materials are required.

It will not be out of place here to notice the progress which has been made in the mechanical appliances for working collieries. No inconsiderable portion of that progress is due to the enterprise of engineers in Leeds. Twenty or thirty years ago, the direct-acting beam engine, usually working without expansion, was the recognised method of pumping. The cumbrous nature of the engine and pit-work, and the great cost of installation, are distinguishing features which must be familiar to all. For ventilation, a huge furnace was kept constantly burning at the bottom of the upcast shaft; and underground haulage was done entirely by means of horses. Both ventilation and haulage are now done by mechanical means. The old non-expansive beam pumping engine is rapidly giving way to horizontal compound engines, applied both on the surface and underground; these work with high pressure and large grades of expansion, and consequently with great economy.

In connection with the engineering of Leeds, it will be interesting to mention the works, now nearly completed, for supplying Leeds with water.

The operations at present in progress consist of the construction of a new reservoir at Eccup, about 5 miles from Leeds, which is intended to contain when completed nearly 1500 million gallons of

water. This is about six months' storage at the present rate of consumption; and as the water will enter in a regulated quantity at one end, and be drawn out at the same rate at the other end, it is anticipated that the purity will be much increased by slow deposition during so long a period.

The water is in the first place obtained from the moors in the valley of the river Washburn, about 16 miles from Leeds, the area of watershed being about 22,000 acres. This water is collected in three reservoirs recently constructed, at Lindley Wood, Swinsty, and Fewston, about 13 miles from Leeds as the crow flies: their respective capacities being 750, 960, and 870 million gallons, with a total water acreage of about 430 acres. From these reservoirs the water gravitates to that at Eccup, through two 30-in. pipes, and from Eccup it flows through a tunnel under Black Moor, and thence by a 40-in. pipe to the filter-beds at Weetwood, whence it is distributed to the several parts of the town. The grand total capacity of the four reservoirs mentioned will be about 4000 million gallons.

The present daily consumption of water averages $7\frac{1}{2}$ million gallons, the population supplied being about 300,000 persons. It may be stated that the average charge for water, collected, stored, transmitted, filtered, and delivered to the consumers in Leeds, is $1\frac{1}{2}d.$ per ton.

From the foregoing description of the practical engineering of Leeds, it will be evident that in this branch of industry the town has always maintained a leading position. Many of the most successful engineers had little opportunity of acquiring the scientific knowledge now deemed essential, and it was mainly by their indomitable energy and perseverance that they succeeded. Of late years however a want has been increasingly felt for a more scientific education, in order to meet the competition of rivals both in this country and abroad. Thanks to the liberality of the inhabitants of the town, and of Yorkshiremen generally, there is a promise of this want being amply met in the future. Already at the Yorkshire College any workman can, for a trifling sum, obtain a first-rate education in pure science; while the engineering chair

enables a study of the higher branches of engineering to be added to the experience gained in the workshop.

Before concluding, the author wishes to take this opportunity of thanking the engineers of Leeds, who have most courteously replied to the questions he has put to them; and he would more especially express his obligations to Mr. Joseph Craven, at whose request this paper was undertaken, and who, by his extensive knowledge of the engineering of the district, has materially lessened the author's labour in compiling the paper. Although from its necessarily superficial nature the paper has done little more than indicate the direction in which engineering has progressed, still it is hoped that enough has been said to show that the progress made in Leeds towards the advancement of engineering, both theoretical and practical, is worthy of the home of Murray, Priestley, Smeaton, Fairbairn, and Greenwood.

ON THE WORKING OF BLAST FURNACES OF LARGE SIZE, AT HIGH TEMPERATURES OF BLAST, WITH SPECIAL REFERENCE TO THE POSITION OF THE TUYERES.

By Mr. CHARLES COCHRANE, of Stourbridge, Vice-President.

Investigations during the past ten or twelve years into the Working of Blast Furnaces in the Cleveland district have been chiefly directed—in the case of furnaces of various capacities, and employing various temperatures of blast—to comparing the fuel consumed per ton of iron made, and the temperatures and relative production of carbonic acid and carbonic oxide at the tunnel head. From these investigations conclusions have been drawn, which were not favourable to the employment of either very large furnaces or very high heats: an impression having once been very general that a furnace of 12,000 cub. ft.* capacity, and with a temperature of blast of 1000° Fahr.,† was in the most favourable conditions for successful working in the Cleveland district. Even so late as 1881, in a Handbook of Middlesbrough and district, this view is advanced, the capacity quoted being only varied by 500 cub. ft.‡

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* See Chemical Phenomena of Iron Smelting, section xxxii., also p. 408.

† See Chemical Phenomena of Iron Smelting, p. 388.

‡ The following is an extract from an article by Mr. Isaac Lowthian Bell, F.R.S., on "The Iron Trade of Cleveland," and "The Industries of Middlesbrough," published in "A Handbook of Middlesbrough and District in 1881," pp. 23, 24, 25:—"Nothing had been ascertained prior to 1850, which indicated that any advantage was to be derived by materially departing from the shape or dimensions of blast furnaces in common use in other localities. Hence those erected on the banks of the Tees, after the discovery of the ironstone in the adjoining hills, had a height of 47 ft. to 50 ft., with a diameter of about 16 ft. at the widest part.

"The ordinary dimensions were first departed from by Messrs. Whitwell, who built a pair of furnaces with a height of 60 ft. Afterwards the late Mr. John

In all the discussions which have taken place, it would appear that two important elements in the successful working of a blast furnace have been overlooked or altogether ignored: namely the size of the hearth, and the overhang of the tuyeres, or, as it may be put by preference, the distance of the tuyeres apart across the hearth. The experience gained by the author during the past eight years, and his special observations during the last two of these, point to the fact that in the employment of high temperatures of blast the distance of the tuyeres apart from nose to nose is of great consequence; and that, *cæteris paribus*, if they approach too close together, the effective

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Vaughan adopted a height of 75 ft., with a diameter of 16 ft. in the widest part. Messrs. Bell Bros. and others followed by increasing the height to 80 ft., with a width of 20 ft. This last change raised the capacity of 6,000 cub. ft. (that of the furnaces of 48 ft.) to 15,000 cub. ft. At the same time more powerful hot-air stoves, and the uniform heat afforded by the combustion of the furnace-gas, gave a blast which registered 1000° Fahr. (538° C.). The united improvement due to these two alterations reduced the coke per ton of iron about 35 per cent., while 15 per cent. to 25 per cent. less limestone was consumed in the blast furnaces.

"Anterior to this, the blast was heated to 600° or 700° Fahr. (315° to 371° C.). The make of each furnace was about 220 tons per week, with a consumption of something like 35 cwt. of coke and 12 to 15 cwt. of limestone per ton of iron.

"Such favourable results led some of the northern ironmasters to expect still better things by the use of still larger furnaces, and still hotter blast. Accordingly furnaces, some more than 100 ft. high, and others not so lofty as these but of greater cubic capacity, have been built; and stoves, as designed by Messrs. Siemens and Cowper and modified by Mr. Thomas Whitwell, were erected, equal to raising the blast to 1400° Fahr. (760° C.). As a matter of general practice however, no economy has resulted from these extraordinary dimensions and very elevated temperature of blast.

"To Middlesbrough however belongs the credit, not only of demonstrating the great advantage arising from the use of furnaces of large dimensions, driven with highly heated air, but of proving the extreme limit to which, in the matter of fuel consumption, these two changes need be carried. A capacity of 12,500 cub. ft., with air at 1000° Fahr., is generally now regarded as effecting all that can be hoped for in reducing the coke required for the blast furnace. Other considerations connected with labour &c. have led many ironmasters to think that a furnace 80 ft. high, with a diameter of 25 ft., containing therefore about 25,000 cub. ft., when supplied with air at 1000° Fahr., is as economical a form as can be devised for smelting the ironstone of Cleveland."

capacity of the furnace is materially reduced. This reduction may easily go so far as to destroy the economy which should have resulted either from extra cubic capacity of furnace, or from extra temperature of blast employed.

In this way a furnace of 20,454 cub. ft. actual capacity has been lowered to only 12,000* cub. ft. effective capacity, and the consumption of coke increased from about 21 cwt. to about 25 cwt. per ton of iron made; in other words a furnace of only 12,000* cub. ft. actual capacity, working efficiently, would have done as good duty as the furnace of 20,454 cub. ft. capacity actually did. Again, in a furnace of 35,013 cub. ft. actual capacity, the effective capacity has been reduced to 18,600 cub. ft., and the coke consumed per ton of iron has been raised from 18·67 cwt. to 20·81 cwt.; besides other unsatisfactory results, consisting in a somewhat diminished make of iron, and the occasional production of an over-grey quality. The *effective* capacity, here spoken of in contradistinction to the *actual* capacity, is estimated in accordance with the curve of furnace capacity and coke consumption drawn in Fig. 7, Plate 57, which will be fully described further on (see page 290).

The writer's observations have extended to four furnaces numbered respectively 1, 2, 3, and 4:—

No. 1.	Furnace	of	33,400	cub. ft.	capacity.
No. 2.	,,	,,	35,013	,,	,,
No. 3.	,,	,,	20,454	,,	,,
No. 4.	,,	,,	20,454	,,	,,

No. 1 Furnace, Fig. 1, Plate 51, was constructed with a hearth of 10 ft. diam., and an overhang of 16 in. of tuyeres; making the distance apart of opposite tuyeres 7 ft. 4 in. across the hearth from nose to nose. It is shown on the sketch with this distance 8 ft. apart, being that at which the tuyeres were placed in February 1882. The furnace was blown in on 18th March 1874.

* As seen from the thick curve in Fig. 7, Plate 57, the effective capacity, at 25 cwt. of coke per ton, is only 7,800 cub. ft., the *loss* in the case mentioned being thus 12,654 cub. ft.; but some remarks in the discussion having turned upon this misprint, it is here allowed to remain in the text.

No. 2 Furnace, Fig. 2, Plate 52, was constructed with a hearth of 8 ft. diam. and an overhang of 12 in. of tuyeres; making the distance apart from nose to nose 6 ft. It was blown in on 10th May 1876. In June 1880 the tuyeres at this furnace were each drawn back 8 in., to the position shown in Fig. 5, Plate 55; making the distance asunder of the tuyeres, from nose to nose, 7 ft. 4 in.

No. 3 Furnace, Fig. 3, Plate 53, was constructed with a hearth of 8 ft. diam., the distance from nose to nose of tuyeres being 6 ft.; and was blown in on 27th November 1876. On 1st March 1882 the tuyeres were drawn back so as to be 7 ft. apart.

No. 4 Furnace, Fig. 4, Plate 54, was constructed exactly as No. 3, and was blown in on 8th January 1880. At the end of January 1882 the tuyeres were drawn back to a distance of 7 ft. apart; with what excellent results we shall presently see.

Fig. 5, Plate 55, shows the section that No. 2 Furnace may be supposed to have assumed about the hearth after four years' wear, or at the time when the tuyeres were drawn back in June 1880: showing only the insignificant increase of 104 cub. ft. extra capacity from the wearing away of the bosh just above the hearth.

In all these figures the dotted lines drawn within the internal outline of the furnace are intended to indicate ideally the currents of gas, as they may be supposed to take their upward course from the hearth to the tunnel head. Where the lines are more numerous, as in Fig. 3, Plate 53, (No. 3 Furnace), they are simply meant to indicate an increased volume of gases passing up through the central area of the furnace. It is not to be supposed for a moment that such lines indicate more than an ideal course of the gases, which are necessarily deflected to right and to left, according as they impinge on one side or other of the materials in their path; but on the whole these lines will give an idea of the directions of the currents, and of the equal or unequal distribution of the whole ascending current over the successive horizontal sections of the furnace. It will not be argued by any one, for instance, that under ordinary circumstances a current tends to work its way from one point of the furnace on the right hand below to another on the left hand above (or *vice versâ* from left to right) as from A to B, Fig. 1, Plate 51.

Commencing then with No. 4 Furnace—the tuyeres of which, till the end of January 1882, had been only 6 ft. apart, and, during the months of February and March 1882, were separated to a distance of 7 ft. apart—the following were the remarkable results obtained.

The make, which had been limited to an average of 483 tons per week, over the preceding months of November, December, and January, rose in March to 599 tons per week; whilst the gross consumption of coke was only increased by 27 tons, or from 603 up to 630 tons per week. The tuyere area was unaltered, being 141 sq. in. total. The temperature of escaping gases at the tunnel head in March was 100° Fahr. less than before the withdrawal of the tuyeres, viz. 617°, whereas previously it had been 717°; whilst the temperature of blast was increased by 109°, being 1321° in January and 1430° in March.

How can we explain the improved behaviour of No. 4 Furnace after the withdrawal of the tuyeres, involving a reduction in the consumption of coke of nearly 4 cwt. per ton of iron produced? Apparently without any other modification than that of drawing back the tuyeres, not only has the furnace subsequently permitted more heat to be carried in with the blast, but the temperature of the escaping gases has been reduced by 100° consequent on the change. It is a well-known fact that in a blacksmith's fire there is a region of greatest intensity, the knowledge of which it is his business to acquire. For our purpose it is sufficient to describe it as that at which the burnt gases, the burning fuel, and the nitrogen of the air have reached their highest attainable temperature, and beyond which they begin to fall in temperature. Some such region there must be in the hearth of a blast furnace; but further (and this is of still greater importance in the solution of the question before us) the result of the tuyeres protruding too far into the furnace is that a larger volume of heated and expanded gases, per sq. ft. of transverse sectional area, must necessarily be delivered up the centre of the hearth than at its circumference. If we consider the form of the hearth, and the temperature and pressure of the gases within it, this point will become clear. In No. 4 Furnace, after the tuyeres had been drawn

back so as to be 7 ft. apart, pressures were observed within the furnace as follows (see Fig. 11, Plate 58) :—

At centre of hearth	$2\frac{7}{8}$ lbs. per sq. in.
At 1 ft. back from centre	3 „ „
At 2 „ „	3 „ „
At 3 „ „	$3\frac{1}{8}$ „ „
At 4 „ *i.e.* inside the muzzle of blast pipe .	$3\frac{1}{8}$ „ „

The pressure of blast at the plug-hole before and after the experiments was $3\frac{3}{8}$ lbs. per sq. in.*

It will thus be seen that there is a steady reduction of pressure from $3\frac{1}{8}$ to $2\frac{7}{8}$ lbs., or a total reduction of $\frac{1}{4}$ lb. from the circumference to the centre of the hearth. A first impression might lead to the supposition that no such extra volume of gases as alleged above could approach the centre; but the fact is that the pressures indicated at various points of the hearth have little to do with the volume there ascending. The totality of those pressures over the whole area of the hearth indicates probably the total resistance of the materials above to the passage of gases; but this total resistance does not prevent a more rapid ascent in one part of the hearth when compared with another. Thus around and above the tuyeres it may be assumed that there is a comparatively still region, in which little or no upward current takes place; and where coke is friable, as it is in some iron-producing districts, it will collect as dust in the quiet corner formed between the projecting tuyere and the wall of the hearth, and will sometimes if not frequently require removal.

A calculation of the volume of blast heated to 1430° Fahr. and compressed to 3 lbs. pressure per sq. in., which passes into No. 4 Furnace when consuming 630 tons of coke and making 599 tons of iron per week, shows that the velocity of each particle of air as it enters the hearth is 457 ft. per second. Were there no obstructions in its path, the air would reach the centre of the hearth of 3 ft. 6 in. radius in 1-130th of a second; but it does meet with the obstruction of the coke undergoing the process of combustion, and it will be

* This part of the subject is resumed on p. 291.

readily understood how, impinging on the surfaces exposed, it will be deflected from its straight course. A little will be thrown back again, some will be thrown downwards on to the surface of the molten slag, and some will continue its onward course with diminishing velocity towards the centre of the hearth, where it will be met by what is deflected upwards from the surface of the slag. This upward deflection of the gases, as they approach the centre of the hearth, is favoured by the form assumed by the surface of the liquid slag, which is higher at the centre than at the circumference by $2\frac{1}{2}$ or 3 in. or more. This is owing to the higher pressure of blast at the circumference than in the centre: a difference of $\frac{1}{4}$ lb. per sq. in. being equivalent to 6·4 in. head of water column, or about $2\frac{1}{2}$ in. head of slag. Should the tuyeres be in too close proximity, as practically occurred in the case of No. 4 Furnace when the tuyeres were only 6 ft. apart, too large a proportion of the gases will be passing upwards through the centre of the hearth, with a higher upward velocity than is to be found at the circumference. The result of this is that, however much the ascending gases in the centre may strive to work their way to the circumference of the bosh, they fail to do so under such circumstances; and so the action of the furnace will be as delineated by the lines shown in Fig. 3, Plate 53. This action is favoured by the central depression of the materials at top, under the charging bell: the line of least resistance being therefore in the central axis of the furnace, in which region the greatest upward velocity occurs. The more closely packed lines towards the centre, Fig. 3, represent the extra volume of reducing gases passing up through the central portion of the furnace.

No one has established more thoroughly than Mr. I. L. Bell the fact that there is a limit to the power of reduction of ore by a mixture of carbonic oxide and carbonic acid gases. When the mixture becomes surcharged with carbonic acid, its reducing action ceases. The central column of reducing gas, created by the proximity of the tuyeres when only 6 ft. apart, must necessarily reduce all the ore in the line of its passage; and although it does not become saturated with carbonic acid, it can yet reduce no more, because no more lies

in its path. But between this central column of reducing gas ascending at high velocity, and the walls of the furnace, there remains an annular space charged with materials needing reduction, but to which the requisite volume of reducing gas cannot gain access. Thus we have the explanation of a large furnace doing only the duty of a smaller one. This arises from the circumstance that the hearth, or rather the arrangement of the tuyeres, has not been duly proportioned to the cubical capacity of the furnace. The day on which the work commenced of drawing back the tuyeres at No. 4 furnace, of 20,454 cub. ft. capacity, from 6 ft. to 7 ft. apart from nose to nose, the slag turned grey, indicating a much higher temperature in the hearth; and it was necessary to cool down the heated blast by an admixture of cold air, until the heavier burden of ironstone and limestone which the furnace ultimately proved itself capable of carrying on a standard weight of fuel, had worked its way down to the hearth. The result of drawing back the tuyeres from 6 ft. to 7 ft. apart was in fact to prevent the centralisation of heat, and to bring about a uniform or more nearly uniform distribution of the ascending gases over the whole transverse sectional area of the furnace, as shown in Fig. 4, Plate 54. Occasionally an accidental, and at the time inexplicable, production of glazed iron took place at this furnace, before the tuyeres were drawn back; and it is believed this was due to an accidental increase of temperature in the hearth through concentration of heat, by which the iron and slag became overheated towards the central part of the hearth, whilst the bulk of the cast would present no exceptional appearance.

Under the altered conditions of the tuyeres, when placed 7 ft. apart, none of the ore is subject to the influence of a greater volume of gas than is needed for its reduction, nor is any deprived of the volume needed to effect its reduction. Thus all the materials arrive at the hearth in a similar condition, equally ready to enter the region or zone of fusion, over the area of which the temperature is practically equable, and the volume of ascending gases per sq. ft. of sectional area is practically the same. It may here be pointed out that the drawing back of the tuyeres of No. 4 furnace was not merely followed by the

combustion of the same amount of coke as before, namely 603 tons,* with an increased output of 91 tons of iron, but there were also produced 25 tons more iron with a consumption of 27 tons more coke, making the total production of iron 599 tons, and the total consumption of fuel 630 tons, in one week. The extra consumption of 27 tons is due to extra "driving," that is, to an extra volume of blast entering the furnace; so that it may be inferred the driving of No. 4 furnace had been restricted slightly, viz. to the extent of 4 or 5 per cent., by the tuyeres being only 6 ft. apart.

The main improvement in the output of iron, namely the increase of the weekly make from 483 tons to 599 tons, was due to the fact that, whereas the 483 tons of iron formerly required 603 tons of coke, or 24·98 cwt. of coke per ton of iron, there are now produced 91 tons extra iron (making 574 tons of iron) with the same weight of coke, and also 25 tons more iron with 27 tons additional coke, due to extra driving. The average total of 599 tons of iron per week was maintained throughout the month of March 1882.

The extra driving may have been, and probably was, favoured by the increased area into which the blast was free to penetrate within the hearth itself, in consequence of drawing back the tuyeres. This increase of area would of course be in proportion to the squares of the distances from nose to nose of the tuyeres, *i.e.* in the proportion of 36 to 49; but it is worth while to note that, whereas the area is thus increased 36 per cent., the increase in driving was only 4 to 5 per cent.; the tuyere area remaining constant at 141 sq. in.

We now proceed to consider the case of No. 2 Furnace (Fig. 2, Plate 52) of 35,013 cub. ft. capacity, 90 ft. high, 28 ft. bosh, with tuyeres 6 ft. apart only, *i.e.* overhanging 12 inches in a hearth originally 8 ft. diameter. The greatest diameter of 28 ft. was attained at a height of only 32 ft. from the floor of the hearth, as shown in Fig. 2. It might be expected that such a furnace would reveal marked

* The average consumption of coke per ton of iron made in March 1882, corrected to No. 3 quality, was 21·01 cwt. For 603 tons of coke this gives 574 tons of iron; against 483 tons of iron, the average of the previous months.

symptoms of the want of diffusion of the ascending gases, under conditions of pressure and temperature of blast like those to which No. 4 was subjected prior to drawing back the tuyeres; and such was the case which actually occurred in No. 2 furnace prior to drawing back the tuyeres in June 1880, the effective capacity being then so low as 18,600 cub. ft., as shown at *f* in Fig. 7, Plate 57. In this case the ascending gases could not spread out laterally fast enough to reach the angle of the bosh efficiently; and the result was the formation of a ring scaffold there. The existence of this however was not positively proved till February 1882, when holes were pierced around the casing at three points of the circumference equidistant from each other, and its existence was established beyond a doubt; this was twenty months after the tuyeres had been drawn back in June 1880, so as to be 7 ft. 4 in. from nose to nose. The effect of this drawing back of the tuyeres was to enlarge the area of the circle inscribed within the noses of the tuyeres in the ratio of 36 to 53·8, giving 49 per cent. more area for the descent of the materials into the zone of fusion, and for the diffusion of the gases. Up to that time, and indeed ever since it had been blown in, No. 2 furnace had worked unsatisfactorily; whilst No. 1 furnace, of the section shown in Fig. 1, with steeper bosh, had never given any trouble. No. 1 had originally a 10 ft. diameter of hearth with 16 in. overhang, leaving the noses of the tuyeres 7 ft. 4 in. apart. In February 1882, holes were pierced in three points of the circumference equidistant from each other, and at the same height (namely 32 ft. above the hearth) as the junction of the bosh with the lining in No. 2 furnace. But the bosh in No. 1 furnace was free from scaffold, and thus confirmed the conclusion already arrived at, namely that the bosh in No. 2 furnace opened out too suddenly, or was at too flat an angle. It will be readily conceded that in No. 2 furnace, prior to the drawing back of the tuyeres in June 1880, the ring scaffold was doubtless larger than it was ascertained to be in February 1882; and that whereas at the present time it represents a reduction of effective capacity in the lower part of the furnace of about 4000 cub. ft., the virtual loss in this region previously might well have been the still larger bulk shown in Fig. 6, Plate 56, viz. 6345 cub. ft. But inasmuch

as the coke consumed prior to drawing back the tuyeres was 20·81 cwt.,*—which betokened that the effective capacity of the furnace (of an actual capacity of 35,013 cub. ft.) was reduced to 18,600 cub. ft. —the total loss may be put at 16,413 cub. ft.; of which 6345 cub. ft. may be explained by the formation of the solid ring-scaffold, and the remainder, 10,068 cub. ft., by the central action of the reducing gases, surcharged with carbonic oxide, but not meeting in their ascent with a quantity of ironstone corresponding with their surplus reducing power. This action is represented in Fig. 2, Plate 52.

As already stated, the tuyeres at No. 2 furnace were drawn back in June 1880, so as to be 7 ft. 4 in. apart from nose to nose. The bosh, as shown in Fig. 5, Plate 55, with its enlarged diameter at plane of junction with the hearth, and its ring-scaffold discovered in February 1882, has consequently assumed approximately the steeper inclination of the bosh originally designed for No. 1 furnace; and the two furnaces have since worked as nearly alike as possible, although both have until recently been working below their full effective capacity, as will be seen by reference to *c* on the capacity-curve in Fig. 7, Plate 57. With a recorded average temperature of blast 73° higher in No. 1 furnace than in No. 2, the effective capacity of both Nos. 1 and 2 furnaces was approximately 25,640 cub. ft., against 33,400 actual in the former case, and 35,013 in the latter.

It may here be stated that this failure to realise the full advantages of these larger actual capacities arose mainly from a reduced blast pressure, through deficiency in steam supply. Now that a steady supply of blast is obtainable, the nearly full efficiency of both furnaces is manifested by the production of a ton of No. 3 iron at No. 1 furnace with 18·70 cwt. of coke, the temperature of the blast being 1406°; at No. 2 furnace by the production of a ton of No. 3 iron with 18·67 cwt. of coke, the temperature of the blast being 1465°.

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* Side by side with No. 2 furnace was working No. 1 furnace of 33,400 cub. ft. capacity; and over a period of five months prior to June 1880 No. 1 worked with 19·94 cwt. of coke per ton of iron, its effective capacity being therefore 24,000 cub. ft., as shown at *d* in Fig. 7, Plate 57, the *loss* in this case being 9,400 cub. ft. The tuyeres of No. 1 furnace were at that time 7 ft. 4 in. apart, as already stated.

Seeing that reference has just been made again to the capacity-curve, Fig. 7, Plate 57, it will be well to explain what is the precise meaning of this curve. In 1870 (Proceedings, Page 75, and Plate 12) a curve was constructed by the author, giving the results of experience obtained at that date at the Ormesby Iron Works, with furnaces up to what was then the largest actual capacity in use at those works, namely 20,624 cub. ft. This curve was extended to show what might probably be the further economy to be obtained by increased capacity up to 40,500 cub. ft. It is indicated by the thin line, which was adjusted to No. 4 quality of iron, being the standard quality to which at that time it was thought proper to refer the working of blast furnaces. The horizontal lines in the diagram are divided into units of cwts. of coke consumed per ton of iron, whilst the vertical lines are divided into units of 1000 cub. ft. of furnace capacity, commencing with 6000 cub. ft. The thick line represents the curve of manufacture under identically similar circumstances to those described in 1870, but adjusted to the production of No. 3 iron instead of No. 4 iron; the correction being made at the rate of $\frac{1}{2}$ cwt. of coke per ton of iron for the difference between Nos. 3 and 4 iron. To quote a single example: whereas in 1870 to make a ton of No. 4 iron in a furnace of 20,624 cub. ft. required 20 cwt. of coke, to make No. 3 would have required $20\frac{1}{2}$; hence the thick line shows $20\frac{1}{2}$, whilst the thin shows 20 cwt. This change has been rendered necessary because No. 3 iron has gradually become the current standard of reference in the district, as the quality at which manufacturers aim, and of which they desire to produce the largest proportion: with the further condition imposed by trade exigencies, that the No. 3 shall include every intermediate shade of greyer grade, from No. 3 up to No. 1, which may not be grey enough for the manufacturers to insist on calling No. 1.

It is in some such way as this—the iron being not only as good as No. 3, but a good deal of it of much better quality, nearly up to No. 1 quality, and therefore using more coke than would be required for No. 3 quality only—that the author considers may be explained the somewhat higher coke consumption of 21·07 and 21·01 cwt. shown

in March 1882,* in comparison with that indicated by the thick curve as the proper duty of Nos. 3 and 4 furnaces, each haivng 20,454 cub. ft. actual capacity. There are in fact two ways of dealing with the results obtained at these furnaces: either by showing them at *g* on the thick line as the standard of reference, in which case the effective capacity of the furnaces appears to have been lowered in that month from their actual capacity of 20,454 cub. ft. down to 17,420 effective capacity;—or, on the other hand, by marking off the results at *e* on the line of 20,454 cub. ft. actual capacity, when the difference of $\frac{1}{2}$ cwt. coke will show how nearly the work of March approximates to the standard of reference adopted in the thick line for No. 3 iron. It happens that Nos. 1 and 2 furnaces in the same month did slightly better than was predicted for them, as shown at *b* and *a*; so that by joining the two extremities thus indicated, a curve is produced intersecting the standard thick curve at a very slight angle, as shown by the dotted curve *a b e*. It could hardly be expected that a perfect coincidence should take place, in dealing with the ever-varying conditions of blast-furnace work; but the approximation is very close, and is rendered the more interesting because the average temperature at Nos. 1 and 2 furnaces during the month of March 1882 was $\frac{1465 + 1406}{2} = 1435^\circ$, and at Nos. 3 and 4 furnaces it was $\frac{1455 + 1430}{2}$ $= 1442^\circ$; whilst the curve of 1870, shown by the thick line, was drawn for an average temperature of 1422°.

An experiment was made to ascertain the distribution of pressure inside the hearth of No. 1 furnace. It gave the following result, the tuyeres being now 8 ft. apart from nose to nose.

Pressure of blast at centre of hearth	$2\frac{3}{4}$ lbs.
" " 1 ft. back from centre	3 lbs.
" " 2 ft. " " "	$3\frac{1}{4}$ lbs.
" " 3 ft. " " "	$3\frac{1}{4}$ lbs.
" " 4 ft. " " "	$3\frac{1}{4}$ lbs.

* The coke this month contained 1 per cent. less ash than usual.

The pressure of blast at the plug-hole was not taken in this case: it would probably be $3\frac{1}{2}$ lbs. Here there is $\frac{1}{2}$ lb. difference of pressure, making the surface of the slag 5 in. higher at centre than at circumference.

In another experiment at this same furnace, the following were the results (see Fig. 12, Plate 58):—

Pressure of blast at centre of hearth	$3\frac{1}{4}$ lbs.
" " 1 ft. back from centre . . .	$3\frac{1}{4}$ "
" " 2 ft. " " " . . .	$3\frac{1}{4}$ "
" " 3 ft. " " " . . .	$3\frac{3}{8}$ "
" " 4 ft. " " " . . .	$3\frac{3}{8}$ "
" " 5 ft., *i.e.* inside muzzle of blast pipe .	$3\frac{1}{2}$ "

The pressure of blast before and after the experiment, taken in the customary way at the plug-hole of the tuyere, was $3\frac{5}{8}$ lbs.

It may be interesting to state in what way these pressures were ascertained. A wrought-iron gas-tube of 1 in. internal diameter and 15 ft. long was armed at one extremity with a movable stopper of wrought iron, as shown in Fig. 8, Plate 58, so that the mouth of the tube should be preserved from being choked when pushed into the hearth, and so that, by the aid of the sharp point, the tube could be the more readily thrust into the centre of the hearth, and sufficiently far beyond it to ensure that on withdrawal the pointed stopper would be left beyond the centre. The mouth of the tube was now perfectly open, and allowed the pressure of gases to operate through the length of 15 ft. of 1 in. tubing. At the outer extremity of this a mercurial gauge was attached, and the successive pressures were promptly recorded as the tube was drawn back a foot at a time; the distances being carefully marked on the outside of the tube before commencing the experiment.

It will be obvious from the foregoing that not only by positive obstructions in the shape of solid scaffolds within a blast furnace can its effective or working capacity be seriously diminished, but that, by the failure to secure a uniform distribution of the ascending gases over the entire area of the bosh, the effect is the same as if such solid obstructions existed. The result must necessarily be extra

consumption of coke in the hearth, to supply the carbonic oxide requisite to act upon the imperfectly reduced ironstone from the outer regions of the furnace. Meantime the gas which should have done this work has passed away at the tunnel head, being in excess of what was actually required for the reduction of the materials through which it passed. There is thus in the escaping gases an increased ratio of carbonic oxide to carbonic acid (or *vice versâ* a diminished ratio of carbonic acid to carbonic oxide), in accordance with the law established practically by Mr. I. L. Bell, and so admirably reduced to the strictness of mathematical formulæ by M. L. Gruner.*

It may well be asked, Is there a limit, and if so what is the limit, to the advantages obtainable by drawing back the tuyeres ?

An experiment on this point was made at No. 1 furnace in February 1882. From a distance of 7 ft. 4 in. apart—the distance with which the furnace had not ceased to work well since the date of blowing in, the hearth being originally 10 ft. diam.—the tuyeres were drawn back so as to overhang only 6 in., leaving their noses 9 ft. apart. No appreciable difference was found in the working. The furnace neither "drove" any faster (that is, it allowed no more blast to enter), nor was there any symptom of economy of fuel. The total area of tuyeres at the time of making this experiment was 170 sq. in., namely six tuyeres with 6 in. diam. of orifice.

Finding that no good resulted from the tuyeres being drawn back so far, they were changed and placed at a distance of 8 ft. apart from nose to nose, at which there is no perceptible difference in the working of the furnace from the time when they were 7 ft. 4 in. apart. No. 2 furnace, a sister furnace already described, is working satisfactorily with the tuyeres 7 ft. 4 in. apart: so that it would appear that for furnaces of such magnitude (90 ft. high, with 28 to 29 ft. bosh, and with $3\frac{1}{2}$ to 4 lbs. pressure of blast) the tuyeres attain their maximum efficiency at and a little beyond 7 ft. apart, the precise distance being a matter of practical observation by the process of trial and error.

* See "Études sur les Hauts Fourneaux," published in 1873, and translated by Mr. L. D. B. Gordon under the title "Studies of Blast-Furnace Phenomena."

In connection with the subject of tuyere area, it may be mentioned that an effort was made to increase the driving of No. 1 furnace with a view to secure better yields than those already attained; but there was soon discovered a limit to the volume of gases which the resistance of the materials in the furnace would allow to pass at a constant pressure. The tuyere area in 1881 was successively increased by enlargement of the six tuyeres to $6\frac{1}{2}$ in. diam. each, and by the addition of a seventh on 20th June 1881. The total area was then 232 sq. in., the noses of the opposite tuyeres being 7 ft. 4 in. apart. Towards the close of the year, *i.e.* about 1st November 1881, the seventh tuyere was removed, and a gradual substitution went on in the replacing of the remaining six by 6 in. tuyeres, thus reducing the area eventually from 232 to 170 sq. in. Just however as the furnace showed no improvement by increasing the tuyere area to 232 sq. in., so it showed no falling off by the reduction back to 170 sq. in. It will thus be clear that, according to the resistance offered by the materials in the furnace, there is a limit to the tuyere area suited to deliver the correct volume of blast corresponding to such resistance—extra pressure of blast being the only means, in such a case, by which extra driving can be obtained.

It is a source of danger to the working of some furnaces to allow this limit of tuyere area to be much exceeded; for if it be much exceeded, any slight obstruction in front of one tuyere determines the passage of the whole or nearly the whole volume of blast through the remaining tuyeres, and the furnace will, by reason of unequal distribution, work more on one side than the other. This leads to irregularities in yield, which go on until the obstruction is removed. As a matter of practice, the writer has seen the necessity of reducing the tuyere area to its proper proportion before a furnace could be restored to its normal working order; the manager for some weeks being unable to hit upon the real cause of the trouble he had to contend with. With such materials as are employed in the North of England, the enlargement of the tuyere area beyond what is needed would in the main tend only to reduce the velocity of the air entering the hearth.

Lastly, on the subject of tuyere area, it is all important to

remember, in the application of high temperatures of blast, that enlargement of the tuyere area must take place according to the extra expansion of the blast due to its extra temperature—if it be desired to drive the furnace at the same rate as prior to the adoption of the higher temperature—in order to allow the increased volume of hotter air to enter the furnace. Thus, according to the law of the expansion of air by heat from 32° Fahr., its volume is increased by $\frac{1}{490 \cdot 6}$ for each degree of temperature attained: in other words a volume of 490·6 cub. ft. at 32° will become 491·6 at 33°, 492·6 at 34°, and at 1000° will become $490 \cdot 6 + 968 = 1458 \cdot 6$; whilst the same volume heated to 1400° will become $490 \cdot 6 + 1368 = 1858 \cdot 6$ cub. ft. Hence to pass 1858·6 cub. ft. into the furnace, under similar conditions to 1458·6 cub. ft., would need an enlargement of tuyere area in the ratio of 1·00 to 1·27, or an increase of rather more than a quarter. Thus if a tuyere were 5 in. diam. when 1000° temperature of blast was employed, it will need to be enlarged to 5·6 in. diam.—or if of $5\frac{1}{2}$ in. diam., it will need to be enlarged to fully 6 in. diam.—in order to provide for the admission of the same weight of blast at 1400° as previously entered through the smaller tuyere at 1000°.

There remains one point to be dealt with in connection with the blast furnace, in order to clear up allusions which have been made to the distribution of temperature in the hearth. It might be thought that, in the plane of the tuyeres, the heat is greater, or not less, in the centre of the hearth than at a short distance from the nose of the tuyere; but this is not so. The author believes the observations he has made on this point will be worthy of record. On thrusting a round bar of 1 in. diam. into the hearth of a furnace, it will be found that if the temperature of the blast be nearly red hot—say 1200° to 1250°—the bar will become actually red hot, as seen by daylight, at a distance of 2 in. from the nose of the tuyere; and that the temperature will rapidly rise until it attains the highest degree at 14 in. from the nose of the tuyere. This temperature is so intense that in the Cleveland district 30 seconds' exposure will nearly

suffice to sever the bar at this point of maximum temperature; from which there is a steady fall through diminishing degrees of temperature till dull red is reached at a variable distance of 8 or 10 in. from the centre of the hearth. The curve is as shown in Fig. 9, Plate 58.

The effect of extra pressure of blast is, as might be expected, to drive in the point of maximum temperature towards the centre; but only to the slight extent of an inch or two for an increase of one pound or more in the pressure of blast. The effect however of diminished temperature of blast in driving this ring of maximum intensity inwards is most marked. Whereas with blast at 1200° to 1300° the ring, as already stated, is at a distance of 14 in. from the nose of the tuyere, if the temperature be lowered to about 350° the ring penetrates inwards to a distance of 17 or 18 inches from the nose of the tuyere.

Being curious to ascertain within what height above the tuyeres this great variation in temperature, as shown in the plane of the tuyeres, might adjust itself to a more equable distribution over the area of the furnace, the author had a hole pierced at about 20 in. above the axes of the tuyeres. It was found, on the insertion of a bar of 1 in. diameter, and its withdrawal after successive exposures of $\frac{3}{4}$ minute, $1\frac{1}{2}$ minute, and lastly 2 minutes, that there was at that level a near approximation to uniformity of temperature in what might fairly be called the zone of fusion.

The author has endeavoured in Fig. 9, Plate 58, to illustrate the intense local heat in the plane of the axes of the tuyeres, and the subsequent diffusion of the heat within a couple of feet above the axis of the tuyeres. The case is chosen of a hearth of 8 ft. diameter, with 6 in. overhang of tuyeres. The highest temperature is reached at 14 in. from the tuyere nose, and it gradually falls off to a red or dull red heat at the centre of the hearth: the initial temperature of the blast being 1300°. At 20 in. above the tuyere axis, the modification which takes place is shown by the much flatter curve; and the author has little doubt that a few inches higher the curve becomes flatter still, until the fusion zone is passed; after which its gradations will depend on the diffusion of the gases over the area of the furnace.

These observations bring out clearly the relative importance of the effects resulting from extra pressure of blast, from diminished temperature of blast, and from closer proximity of the tuyeres. Thus an extra pressure of about 1 lb. in blast at same temperature pushes the point of greatest intensity only an inch or two inwards. If the temperature of blast be lowered to 300° or 400°, the point of greatest intensity is pushed in 3 or 4 in., so as to be 17 or 18 in. from the nose of the tuyere instead of 14 in. But if the tuyeres themselves be pushed in, the direct effect is to reduce the diameter of the hearth by the same amount; so that when, as was actually the case at Nos. 2 and 4 furnaces under the conditions described in this paper, the tuyeres were only 6 ft. apart, the diameter of this circle of most intense action was diminished from 4 ft. 8 in. to 3 ft. 8 in.; and an intense upward central movement of the gases was the result, the ring of greatest heat being thus prejudicially forced inwards towards the centre of the hearth, as in Fig. 10, Plate 58.

It may be necessary to state that in all the observations recorded in the course of this paper the materials operated upon were practically the same, in mechanical and chemical conditions, as those which were referred to in the paper of 1870. The coke contains about 9·23 per cent.* of moisture, sulphur, and ash, whilst about 48 cwt. of calcined ironstone and 12 cwt. of limestone are needed to produce 1 ton of iron: the calcined ironstone containing only about 41 per cent. of iron.

In giving the above facts and conclusions, the author has abstained from any reference to the analysis of gases at the tunnel head; because such analysis cannot be treated as an absolute guide to the working of a furnace, valuable though the information so obtained is as a help to understanding the duty that is being performed. No analysis of gases could have led to the discovery of the detrimental effect on the working of a furnace, due to having the tuyeres in too close proximity; whilst this discovery will explain many of the contradictions and anomalies which have existed in the

* In March 1882 this percentage was only 8·20.

past. One instance may be quoted from a remark made by that eminently practical ironmaster, Mr. Edward Williams,* which is itself appealed to in Mr. I. Lowthian Bell's treatise on the Chemical Phenomena of Iron Smelting.† "We have," observes Mr. Williams, "close together, at the Eston furnaces, one of 15,000 ft. capacity, one of 20,000 ft., and another of 27,000 ft.—all using precisely the same ironstone, with fuel from the same colliery; and, so far as we are able to judge, there is no economy of fuel in the larger furnaces." He goes on to say, "This is quite certain, that, in my case, beyond 11,000 or 12,000 ft. capacity there is no saving of coke per ton of iron made."

Abstract of Discussion on Blast-Furnace Working.

Mr. COCHRANE wished to add a few observations with reference to the diagrams, Figs. 1 to 5, Plates 51 to 55. At the top of the furnace he had drawn lines showing practically the arrangement of the materials as they adjusted themselves under the charging bell. He had had a bell arranged for the purpose, and he was astonished at the flatness of the surface which the materials, shooting off from the bell, assumed in going against the side of the furnace. The line shown for the surface of the materials thus represented what was actually found in practice. It was admitted, he believed, that the taller furnaces in the Cleveland district had usually shown, in relation to their cubic capacity, better results than shorter furnaces of greater width. This was confirmatory of the conclusions at which he had arrived, inasmuch as in a furnace narrower in proportion to its height there was less room left for the waste which he had described as taking place between the central column of intense action and the circumference. He had been asked

* "Iron and Steel Institute Journal," May 1870, pp. 35–36.

† "Iron and Steel Institute Journal," 1871, vol. i., pp. 352–3.

what height he had taken in the furnaces in calculating their capacities. There was no definite standard adopted for calculating capacities; and he had done himself a little injustice by giving the total capacity of the furnace right up to the underside of the bell, when closed up against its seat. Possibly in the calculation an allowance should be made of 1350 cub. ft. in the larger furnace, and 950 cub. ft. in the smaller, to give their real capacities. Again it would be obvious that the tuyeres might be placed at distances intermediate between the 6 ft. and the 7 ft. apart mentioned in the paper; and that certain small variations in economy would in all probability be established, were there any object in discovering the actual saving for every inch increase in their distance apart. He had been anxious however to get the best results as quickly as possible. With regard to the financial economy of his results, he might say that the drawing back of the tuyeres to the extent of 6 inches on each side of the furnace was worth annually £3,000 in the saving of fuel alone.

There was another matter to which a friendly critic had called his attention—that while describing, p. 294, the effect of an increased area of tuyeres up to 232 sq. in. total, he had omitted to take cognisance of the fact that he had still only a pipe of 15 in. diameter to convey the blast up to the furnace, and that this would give only about 177 sq. in. area. But the case was not that of discharging blast into an open space, but was different altogether. It was possible that by enlarging the tuyere area the resistance at the orifices would have been reduced; and then, though the blast was still passing through a pipe of only 177 sq. in., the velocity in that pipe would have increased, and more blast would have entered the furnace. The negative result showed that the conditions within the furnace prevented the larger area of the tuyeres from operating to induce a larger volume of blast. With regard to the results that had been given for March, p. 289, he was pleased to say that they were confirmed by the subsequent results of April, May, and June. In May more excellent results still had been attained in No. 1 and No. 2 furnaces: namely, in the former 18·34 cwt. of coke, and in the latter 18·45 cwt. of coke per ton of No. 3 iron; with a make of 2,508 tons for the month of May in No. 1 furnace, and 2,414 tons in No. 2.

Mr. I. LOWTHIAN BELL considered that to no one was the iron trade more indebted, for the spirit and even boldness with which the use of superheated air in the blast furnace had been taken up, than to Mr. Charles Cochrane, from whom consequently they were always glad to hear anything on this interesting and highly important question. The present paper dealt with the subject in the most advanced form hitherto presented; for, taken in conjunction, the blast was hotter and the furnaces were larger than were in use anywhere else. Under these circumstances it was perhaps to be regretted that the author should not have extended his observations on the general question: instead of dealing—to the exclusion of more important matter—with a mere condition of things which seemed to have interfered with his deriving the full benefit of the extraordinary powers at his command.

In regard to the title of the paper, which spoke of the working of blast furnaces of large size at high temperatures, he was not prepared to admit that their temperature was necessarily superior to that of any other furnace producing the same quality of iron; and he presumed the meaning really was that they were blown with air at high temperatures.* He mentioned this because he should hereafter show that the author was not deriving as much heat from each unit of coke burned in a furnace of 20,500 cub. ft., blown with air at 1400° Fahr., as could be and was obtained in furnaces of about half that capacity with blast at 1000°. There was this difference between the two cases, that at Ormesby more of the heat evolved was due to the blast and less to the coke; but he would later on endeavour to prove the truth of the assertion he had just made.

It would seem from the paper that by drawing back the tuyeres in a furnace of 76 ft. height and 23 ft. diameter, containing about 20,500 cub. ft., an economy of close on 4 cwts. of coke per ton of iron made had resulted, with an increase of 116 tons in the weekly make. The hearth had a diameter of 8 ft., and the tuyeres were originally 6 ft. apart across it; this distance was increased to 7 ft.

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* *Note by the Author.* This has now been made clear by using the words "temperatures *of blast*" in the title of the paper.

by the alteration, each tuyere having been moved 6 ins. further out from the centre of the furnace. An economy, greater or less in its amount than the above, having been obtained in other furnaces, it must he supposed be admitted that originally these tuyeres must have been too far advanced into the furnace. At the same time he should scarcely have thought that drawing them back 6 ins. could have been followed by so great a reduction as 16 per cent. in the coke consumed, unless it were by the removal of scaffoldings. This was explained in the paper by supposing that, when the tuyeres were only 6 ft. apart, the carbonic oxide which had to effect the reduction of the ore had not reached the outer portions of the furnace contents, and thus had permitted a certain quantity of partially reduced oxide of iron to reach the lower regions of the furnace, which was always undesirable. There might be something novel in working with overhanging tuyeres such furnaces as were described in the paper; but his own experience was that the position of the tuyeres after their alteration at Ormesby was not far from the same as generally adopted in Cleveland. On the other hand it was conceded in the paper that this explanation was only an ideal one; but it would have been more satisfactory had samples of gas been withdrawn at different levels, the composition of which would at once have determined whether reduction had been postponed in the manner imagined.

There was one circumstance named in the paper which was certainly contrary to his own observations, namely the pressure which the blast maintained to the centre of the hearth: the difference being only $\frac{1}{4}$ lb. per sq. in. between the pressure inside the muzzle of the tuyere and that at the centre of the hearth, a distance of 3 or 4 ft. from the orifice of the blast pipe. Many years ago he had made this very question the subject of enquiry; on reading the results given in the paper he had the experiments repeated, and they entirely confirmed those he had made on the former occasion. In the Clarence furnaces of 80 ft. height, the very instant the air was clear of the blast pipe its pressure fell from $3\frac{1}{2}$ down to $1\frac{1}{2}$ lb. per sq. in., which lower pressure was maintained uniformly over the entire sectional area of that part of the furnace. Whether there were anything in the use of superheated air which could localise areas

of temperatures, so as to render the materials more impervious to the blast, he could not say; but it seemed pretty evident that there was something unusual in the facts as laid down in the paper, respecting internal pressure. Instead of the surface of the slag rising in a cone towards the centre of the hearth under the pressure of the blast, as stated in the paper, his own impression was that it rose towards the dam, over which the outflow of slag continued so long as the blast remained on; because as a rule, when the blast was taken off the furnace, the slag instantly ceased running over the dam.

Reference had again been made by the author to a curve described by him seven years ago, by which it was sought to be proved that a furnace of 20,454 cub. ft. had its effective capacity lowered to only 12,000 cub. ft.* because it consumed 24·98 cwts. of coke for each ton of iron produced, although receiving its blast at above 1400° Fahr. He would submit however that something more was needed than the curve referred to, before it could be agreed that a furnace of 12,000 cub. ft. necessarily required any such quantity of coke as that here assigned to it; and on the occasions of Mr. Cochrane's former papers read before this Institution the correctness of any such law as that now laid down had been distinctly questioned by himself. The present paper did him the honour of quoting at some length language he had made use of so late as last year, when he had mentioned that "a capacity of 12,500 cub. ft., with air at 1000° Fahr., is generally now regarded as effecting all that can be hoped for in reducing the coke required for the blast furnace." It might be that more recent experience would render it necessary that this opinion should undergo a little modification, and that it might be desirable to be more careful in future prophecy: of the extent of his error he would speak presently. The correctness of what he had said in 1881 was questioned rather by implication than in express terms; but he certainly gathered from the paper that the author did not agree with the views quoted in the footnote of page 279. In that

* For correction of this figure in the paper, see footnote to page 281; also remark in Mr. Cochrane's reply, page 315.

quotation however it must be borne in mind that he (Mr. Bell) had undertaken the part of historian, and all he could do was to deal with historical facts as he found them at the time. In this particular matter, to what authority could he turn with greater propriety than to the author himself, who had larger furnaces blown with hotter air than any other ironmaster? In the author's former papers in 1870 and in 1875 the subject was fully gone into, and information was given as to what had been done over a period of three or four years, in furnaces of from 20,600 to 40,500 cub. ft., blown with air from 1200° to nearly 1400° Fahr.; and the average appeared to have been above 23½ cwts. of coke per ton of iron made. In the present paper a good deal of reference had been made to the curve of effective capacity; from which it was made out that the 23½ cwts. given as the actual consumption ought to have been only 21·15 cwts. if the furnaces had been working properly. On the former occasion he had questioned the grounds upon which this curve was laid down; and he believed he had distinctly stated that the Clarence furnaces of 11,500 cub. ft., blown with air at 1000° Fahr., were doing better than had been done or was doing at that time by the Ormesby furnaces of 20,000 or even 40,000 cub. ft. with air of nearly one half higher temperature. He was therefore at a loss to understand why, when furnaces at Clarence were then doing better than 23½ cwts. of coke per ton of iron, 12,000 cub. ft. should be assigned as the effective capacity of a furnace, because at Ormesby another furnace of 20,000 cub. ft. was consuming 25 cwts.

The concluding paragraph of the paper, p. 297, mentioned that the author had abstained from any reference to the analysis of gases at the tunnel head, because such analysis could not be treated as an absolute guide to the working of a furnace, and could not have led to the discovery of the detrimental effect on its working, due to having the tuyeres in too close proximity. In the general soundness of the last proposition he concurred; but he entirely dissented from the first, for he regarded the composition and temperature of the gases as an infallible guide in judging of the working of a furnace—sometimes indeed more to be relied on than estimates based on the charging book itself. He regretted the position of minor importance assigned

by the author to a study of the composition of the gases, because by his kindness he had been permitted to take specimens of the gases from both varieties of the Ormesby furnaces mentioned in the paper. The gases were collected over a period of two hours from each furnace, and on two different occasions, so as to ensure their representing an average; and were then carefully analysed by Mr. Rochell at the Clarence laboratory. The results he had communicated to Mr. Cochrane, whose opinions on the facts they disclosed he had been most anxious to hear; and he would venture now to submit some of these results to the meeting, in the hope that the author might say a few words on a branch of the question of which he seemed to underrate the importance.

Mr. COCHRANE pointed out that the gases analysed by Mr. Bell were taken off from the Ormesby furnaces in November 1881; and the analysis therefore could not bear upon the results communicated in the paper, with reference to the working of No. 4 furnace *after* the alteration had been made of drawing the tuyeres back in January 1882. He hoped however that Mr. Bell would say something more about the consumption of coke, to which he had referred when alluding to the furnace of 12,000 cub. ft. capacity.

Mr. E. WINDSOR RICHARDS hoped the composition would be given of the blast-furnace gases analysed by Mr. Bell; because that was a most important matter, even independently of the special purport of the paper.

Mr. BELL resumed that, from an examination of every function performed by the blast furnace, he had estimated that, exclusive of the heat carried off in the gases, from 84,500 to 86,000 calories or centigrade thermal units were absorbed, less or more, in producing 20 cwts. of Cleveland pig iron. He specified Cleveland pig, because different kinds of pig iron varied a little in composition; and in the round numbers just quoted he avoided exactness, because iron ores varied in richness and in the quantity of flux they required.

The general correctness of these figures might be verified by two examples from his work on Iron-smelting, in which under very different circumstances there was a close approximation in the heat actually absorbed. It must be borne in mind that the quantity of heat developed by carbon depended on the extent to which it was oxidised; for while each unit when burnt to carbonic acid evolved 8000 calories, it afforded no more than 2400 when burnt to carbonic oxide only. Owing moreover to the reducing condition which had to be maintained in the gases of an iron furnace, as alluded to in the paper, the proportion of carbon brought to the highest state of oxidation—that of carbonic acid—was limited in his opinion to one-third of the whole; this he conceived to be the extreme limit, but the proportion was often less; that is, instead of finding 1 of carbon in the gases as carbonic acid to 2 as carbonic oxide, it was often 1 to $2\frac{1}{4}$, and sometimes 1 to 3 or even more. The two examples he would quote were those of an old Cleveland furnace of 48 ft. height and 6000 cub. ft. capacity, and a modern one of 80 ft. height and 11,500 cub. ft. capacity, their consumption of coke being respectively 28·9 and 22·3 cwts. per ton of iron made. The heat generated and utilised was estimated from the composition of the escaping gases to be as follows per unit of coke burnt:—

	Short Furnace. Calories.	Tall Furnace. Calories.
Heat evolved by combustion of coke	3089	3656
Heat in blast	508	539
Total heat generated in furnace	3597	4195
Heat carried off in escaping gases	640	397
Net heat utilised in smelting	2957	3798

Multiplying these numbers by the respective consumptions of coke, the total heat appropriated in smelting one ton of pig iron was found to be—

Short furnace, 28·9 cwts. coke × 2957 calories = 85,457 calories.
Tall ,, 22·3 ,, ,, 3798 ,, = 84,659 ,,

The difference of 798 calories could be easily accounted for, did time permit.

The Ormesby No. 3 furnace, which he had visited in November 1881, was said to be using at that time 24·15 cwts. of coke per ton of iron made, the tuyeres being then in an unfavourable position. This quantity however he believed to be in excess of the actual consumption, firstly because the calculation founded upon it brought out too high a number of calories, and secondly because an estimate derived from the composition of the escaping gases themselves indicated 22·35 cwts. as nearer the true consumption. Placing side by side the performance of this furnace in last November, and that of a Clarence furnace of 11,500 cub. ft. capacity, as now working for some years past, the two would compare as follows, each making the same quality of iron:—

	No. 3 Ormesby.	Clarence.
Capacity of furnace, cubic feet	20,400	11,500
Temperature of blast, Fahr.	1569°	1045°
" " escaping gases, Fahr.	507°	504°
Units of carbon in carbonic oxide for each unit in carbonic acid	3·70	2·22
Weekly make of pig per 1000 cub. ft. capacity, tons	24¼	30
Coke consumption per ton of pig, estimated from charges, cwts.	24·15	20·40
" " " " " " gases, cwts.	22·35	20·49

Total Heat per unit of coke burnt.	Calories.	Calories.
Heat evolved by combustion of coke	3091	3580
Heat in blast	780	574
Total heat generated in furnace	3871	4154
Heat carried off in escaping gases	251	258
Net heat utilised in smelting	3620	3896

Multiplying these numbers as before by the coke consumed, the total heat appropriated in smelting one ton of pig iron was found to be—

Ormesby, 22·35 cwts. coke × 3620 calories = 80,907 calories.
Clarence, 20·40 " " 3896 " = 79,479 "

Here again the difference of 1428 calories, or only 1·8 per cent., as well as the smaller quantity of heat in comparison with the former instance he had given, admitted of easy explanation. As already mentioned, each unit of coke, although burnt with superheated air,

might afford less heat than when air of a more moderate temperature was used; and a confirmation of this statement was furnished by the figures just given.

With regard to the composition of the escaping gases, which had been asked for by Mr. Richards, the analyses were as follows, by weight:—

Ormesby No. 2 furnace of 35,013 cub. ft. capacity.

Date.	15 Nov. 1881.	29 Nov. 1881.
Temperature of Blast .	1357° Fahr.	1507° Fahr.
Carbonic Acid . . .	18·70 = 5·10 carbon	18·36 = 5·07 carbon
Carbonic Oxide . .	25·17 = 10·79 carbon	26·66 = 11·42 carbon
Hydrogen . . .	0·01	0·07
Nitrogen	56·12	54·91
	100·00	100·00

Ormesby No. 3 furnace of 20,454 cub. ft. capacity.

Date.	15 Nov. 1881.	29 Nov. 1881.
Temperature of Blast .	1630° Fahr.	1569° Fahr.
Carbonic Acid . . .	14·45 = 3·94 carbon	13·42 = 3·66 carbon
Carbonic Oxide . .	28·32 = 12·14 carbon	31·66 = 13·57 carbon
Hydrogen . . .	0·20	0·12
Nitrogen	57·03	54·80
	100·00	100·00

One unit of carbon as carbonic acid appeared therefore to have been accompanied by the following quantities of carbon as carbonic oxide:—

	15 Nov. 1881.	29 Nov. 1881.
No. 2 furnace of 35,013 cub. ft. capacity . .	2·11	2·25
No. 3 „ 20,454 „ . .	3·08	3·71

With regard to the performance in November 1881 of the larger Ormesby furnace, No. 2, having a capacity of 35,000 cub. ft. and receiving blast at temperatures varying from 1357° to 1507° Fahr., his examination had shown that it was then making iron with somewhat less fuel, though not much less, than the Clarence furnaces of 11,500 cub. ft. capacity had been doing for the month of July 1882. There was also a close approximation between the coke consumption

in the Ormesby No. 2 furnace according to the charging book, namely 19·69 cwts. per ton of pig, and the consumption which he had calculated from the composition of the escaping gases, namely 19·89 cwts. At the time of his analysis in November last, the weekly make of iron from that large furnace amounted to only 15 tons per 1000 cub. ft. of furnace capacity, which was only half the make of the Clarence furnace. Taking the coke consumption estimated from the charges, the advantage of this 35,000 cub. ft. furnace over that of 11,500 cub. ft. was less than $\frac{3}{4}$ cwt. per ton of pig, and this was obtained with air about one half hotter and at a sacrifice of one half of the furnace's proper production.

Since his visit to the Ormesby Works in November last, it appeared from the paper that iron had been made there with as low a consumption as 18·7 cwts. of coke per ton in one of the larger furnaces, (which it might be observed had had its original dimensions reduced from 40,500 to 35,000 cub. ft.) Having no information as to the composition of the escaping gases with this lower coke consumption, all he could do was to consider what the working of the furnace must be, in order to furnish say 81,000 calories, which had been seen to be the total heat appropriated per unit of coke burnt. Assuming for the escaping gases the most favourable composition that he had met with in smelting grey iron from Cleveland ironstone—namely 1 unit of carbon as carbonic acid to 2·10 units in carbonic oxide—, and regarding the coke as containing 90 per cent. of carbon, the heat evolved per unit of coke burnt would be $\frac{1 \times 8000 + 2{\cdot}10 \times 2400}{3{\cdot}10} \times \frac{90}{100} = 3785$ calories; from which must be deducted 255 calories carried off in the escaping gases, leaving 3530 calories applicable to the actual work of the furnace. Now

Coke consumption of 18·7 cwts. × 3530 calories =	66011 calories.
Leaving the blast to supply	14989 „
In order to make up the required total heat of .	81000 „

In order to contain the required 14989 calories, the blast, weighing 90 cwts., would have to be at a temperature of about 1300° Fahr. Hence, admitting the escaping gases to have this somewhat

unusually low proportion of carbonic oxide—which was perhaps problematical,—it did not appear impossible to work at even as low a consumption as 18·7 cwts. of coke per ton of pig. This economy however was only $1\frac{1}{4}$ cwt. better than what was being done at this very time in very much smaller furnaces, making fully twice as much iron for their capacity. On a former occasion a good deal had been said by the author about reducing the coke consumption to 17·9 cwts. per ton of iron; but it must not be forgotten that, in diminishing the quantity of coke, the quantity of blast would be reduced also; and if at the same time the heat contributed by the blast had to be increased, the temperature of the blast would have to be very largely raised, and the blast would attain a temperature beyond the power of endurance of the apparatus used in conducting it.

Throughout this argument it would be perceived he had been considering the existence and the effect of certain natural laws, and had been endeavouring to prove, both by these and by actual experience, that the author was mistaken in some of the conclusions laid down in the paper. For if one of the Clarence furnaces of 11,500 cub. ft. capacity could for months and years make iron with a very considerably lower quantity of coke than had been assumed in the paper, what became of the theoretical curve of effective capacity? So far indeed as superheated air was concerned, he was ready to concede that the figures he had been making use of were more favourable than those which represented the average performance of furnaces using blast of say 1000° Fahr. Looking at the vicissitudes in the life of a blast furnace, he was by no means insensible to the advantages that might be derived from possessing the power of heating the blast to a temperature which could not be commanded by the use of metal-pipe stoves. Admitting however the performance of the Clarence furnace of 11,500 cub. ft. capacity to be exceptional, and its coke consumption to be exceeded by the average of the Cleveland district, the fact should not be lost sight of that the data on which to found a computation of averages for superheated air were still very limited, and in his own experience were very much less favourable than those mentioned in connection with the Ormesby furnaces.

In the present paper he considered too strong a case was made out in favour of superheated blast, not so much by any sanguine expressions in respect to its merits as by depreciation of air more moderately heated. At the same time he thought anyone erecting blast furnaces ought not to lose sight of the valuable information afforded by the author from time to time on this very important question. Individually he himself felt greatly indebted to him for this, as well as for the opportunities he had afforded him of studying the subject at the Ormesby Works.

Mr. E. A. Cowper wished to draw attention to the statement on page 289 of the paper, that the consumption of coke in a large furnace was only 18·7 cwt. per ton of iron, with a very high temperature of blast; this was confirmed by the further experience obtained during several succeeding months with the two furnaces in question—the consumption during the last month being only 18·45 and 18·34 cwt. of coke per ton of iron, and the make being over 600 tons per furnace per week. The consumption in hæmatite furnaces was as low or lower. There was another point, on which he should be glad of more information, namely the result obtained by increasing the pressure of the blast; he did not mean by an increase of only 1 lb. or so, but by 4 or 5 lbs., so that the pressure in the furnace should be 6 or 8 lbs. per sq. in. He had long held that with a large hearth the pressure of blast must be high in proportion, in order to penetrate the material and produce the best result. In one of the Edgar Thomson furnaces in America they were now producing 1800 tons per week, with a high temperature and high pressure of blast, and with a large hearth. He would venture to suggest that the alternate tuyeres should overhang by a different distance, so as to distribute the blast better over the area; he was aware that tuyeres had been put at different levels, but that was a separate question.

Mr. E. Windsor Richards desired to say a few words with regard to the effect of large capacity upon the economical use of coke in a blast furnace. He thought if the author's curve, Fig. 7,

Plate 57, was constructed without regard to the height of the furnace, it would be a very misleading one to follow. He could confirm the remarks of Mr. Williams which were quoted at the end of the paper, as to the effect of capacity in the case of furnaces at Eston. Those same two furnaces were working at present upon hæmatite iron; and there were also two furnaces of similar capacity working upon Cleveland iron. In one pair the bosh was 20 feet diameter, and in the other 25 feet, and the heights were 95 ft.: but there was absolutely no difference whatever in the economy of coke per ton of pig iron made in the two capacities of furnace.

At page 283 it was asked, "How can we explain the improved behaviour of No. 4 furnace after the withdrawal of the tuyeres, involving a reduction in the consumption of coke of nearly 4 cwt. per ton of iron produced?" That result certainly could not be attributable, in his opinion, merely to the drawing back of the tuyeres to 7 ft. apart; it was quite out of the question. The author might have put the same question with regard to No. 3 furnace, which was precisely the same size as No. 4, and in which the tuyeres were 6 ft. apart; but the results with that furnace were not given.

He should like to give some dimensions of two furnaces in Cleveland, in order to show the saving effected by increased height. The figures had been given by Mr. Edwin F. Jones—a most careful blast-furnace manager, as those who knew him would admit. The furnaces were 60 ft. high, and they used 24·95 cwt. of coke per ton of pig iron made. They were afterwards raised 15 feet, which of course slightly increased their capacity; and with the same ironstone and the same quality of coke there was then a saving of 2½ cwt. of coke per ton of pig iron, due to their increased height.

With regard to high temperatures of blast, he had lately had a little experience with Cowper fire-brick stoves giving a very high temperature, and he could confirm the statement of its good effects upon furnace working. He thought no one doubted the great economy of raising the blast temperature from 1000° up to 1400° in low furnaces; but there was a question as to the economy in high furnaces. He had only begun work on the previous Friday, so he

could not at present give any very reliable information; but as far as it went it showed the good effect of a high temperature on high furnaces, say those at and above 80 feet. Four stoves were applied to two furnaces, 95 feet high, and the blast temperature by Sunday had risen from 1000° up to 1200°. One of the furnaces had previously been making forge iron (hæmatite), and the other mottled and white Cleveland iron. On Sunday, after having worked 48 hours, the quality of the forge iron had run up to No. 1; and the mottled and white had gone up to No. 3; showing that an increase of only 200° had effected an improvement. It was necessary to increase the burden of ore; in the hæmatite furnace it was increased 4 cwt. to the round, and in the Cleveland furnace 2 cwt. to the round.

The position of the tuyeres was no doubt a very important matter, but not he thought in the sense stated by the author. Their practice in Cleveland was to push the tuyeres about 16 or 18 inches into the furnace. The object of that was to prevent the furnace working hot on the breasts. He did not think the position of the tuyeres had any influence upon the economy of the fuel. If the tuyeres were pushed in say 18 inches, the furnace worked cooler, and there was less liability for the iron to break out.

Some figures which he had lately obtained from the Edgar Thomson Works, at Pittsburgh, in America, might perhaps be interesting, as showing the work that was being done there; they had been supplied by Mr. Andrew Carnegie. The dimensions of the furnace were: 20 ft. diameter of bosh, 11½ ft. diameter of hearth, 80 ft. height; tuyeres pushed in only 6 inches. In the week ending 24th May last, the furnace made 1642 tons of No. 3 foundry iron for Bessemer purposes, and it consumed only 20·83 cwt. of coke per ton of iron made. The ore yielded in the furnace 55 per cent. of metallic iron. The blast temperature was 1200°. In one period of 24 hours, on 26th May, the make was 299 tons.

Mr. Edward Williams enquired whether any of the furnace was still in existence.

Mr. Richards said the make was still going on, but the amount

would not be kept up, because another furnace had since been put into blast. There were two furnaces, D and E, and in May the latter was not quite ready to start. Four blast engines were therefore turned on to furnace D, which then received, he believed, some 35,000 cub. ft. of air per minute. The furnace was lined with plates, having water circulating all round about the lower part and for several feet above the level of the tuyeres. It was believed that the furnace would last two years without re-lining, and that was thought to be a very good life in America.

Mr. Bell fully agreed with Mr. Richards as to the great value of a high temperature of blast in low furnaces, its importance arising from the simple reason to which he had already referred: namely that, as the quantity of coke burnt per ton of pig in a furnace was diminished, the quantity of blast required was necessarily diminished also. In consequence of this change of conditions, the quantity of gaseous matter rising through the furnace was a good deal less, for a given weight of metal, than when more blast was used. Thus a consequence of using a hotter blast was to diminish the volume of gases passing up through the furnace, and therefore their velocity. In such an event there was a diminished volume of reducing gas, but of a higher temperature, and with a less velocity; hence it had a longer time, by virtue of this reduced velocity, to do its work and to impart heat to the solid materials exposed to its influence, than during a more rapid ascent towards the throat. When however the furnace was capacious enough, in reference to the duty to be performed as regards the objects just mentioned, this extra time was not needed, and the heat in the blast meant so much heat, and nothing more. Hence the greater value of superheated air in a lower furnace than in a higher one. How hot the blast could be made was a matter that rested with the fire-brick stoves. To bring down the coke consumption to 15 or 16 cwts. per ton of Cleveland pig, he believed the blast would require to be heated up to 2500° Fahr., which was about the melting point of cast-iron; and not only therefore would it be impossible to convey so hot a blast through any apparatus made of cast-iron, but there was in addition the further

difficulty arising from the slowness with which fire-brick conducted heat; whence he very much doubted whether it would be possible during any length of time to maintain a blast much beyond 1500° or 1600° Fahr.

A Cleveland blast-furnace ought in his opinion to be making weekly at least 30 tons of iron per 1000 cub. ft. of capacity, instead of only the 15 tons made by the large Ormesby furnace in November last. There were few ironmasters who, having a furnace of given capacity, would not rather make a larger quantity of iron (seeing how expenses were thereby reduced in other directions) than make a smaller quantity, even though with a little lower consumption of coke. But with regard to the enormous make reported from Pittsburgh by Mr. Richards, he could well understand Mr. Williams' question whether the furnace was still there: he might indeed be inclined to doubt whether such was the case. For in point of fact he was inclined to think that the durability of a furnace was not determined by weeks or months or years, but by the quantity of iron made. Certainly in the case of the Isabel and Lucy furnaces at Pittsburgh, which had each been making 1200 tons of iron a week, the result had been that the furnaces were entirely worn out in two years. It should be remembered that the establishment expenses—so far as concerned engines, railway conveyance, labour, and in fact everything but the mere shell of the blast-furnace—bore a direct ratio to the weekly make of iron: if twice as much iron were being made, twice as much blast would be required, and so on; so that the only saving was in the interest &c. on the cost of the furnace shell, which was after all only a small portion of the general cost of the establishment. Was it not therefore more prudent to have a larger furnace and drive more slowly, rather than to attempt getting the enormous makes which had been reported from America?

Mr. Cochrane said, before replying to the observations made by Mr. Bell, he would remark that he had endeavoured to make the paper as thoroughly a *mechanical* paper as possible, and had avoided any reference to details of chemical phenomena within the furnace itself, in order to limit the paper to those mechanical points to which he had

drawn attention. He felt that in declining, as he did decline. to answer Mr. Bell on points of chemistry, it might almost appear as if he could not do so; but no one knew better than Mr. Bell himself that, in dealing with such points, every circumstance of the furnace—from the admission of the blast at the bottom to the escape of the gases at the top—must be taken into consideration, in order to do justice to the question. He therefore trusted that he might be pardoned if, at the risk of appearing unable to answer Mr. Bell, he avoided that part of the subject: conceding to him however one little point, namely that so abnormal were the circumstances of the furnace at the time of Mr. Bell's visiting it in November 1881, that he was himself unaware of the quantity of cold blast thrown into it from time to time in order to correct the very irregularities to which the paper had drawn attention. The saving he had mentioned, of 4 cwt. of coke, would no doubt require a slight diminution on that account. But he could not allow Mr. Bell to sweep away 2·63 cwt. from the figure of 24·98 cwt. (p. 287), and to say that 22·35 cwt. of coke per ton of pig was what his furnace had been working at. He knew the furnace ought not only to do that, but to do a great deal better; indeed it had subsequently done a great deal better; and it was the endeavour to explain how the better result had been obtained that had produced the present paper. This paper he had offered to the Institution of Mechanical Engineers, because he desired that his latest observations on this subject should be recorded in the same Proceedings which had so carefully recorded whatever he had done previously in reference to blast furnaces. He must remark however that it had been simply a clerical error in the first proof of the paper (page 281) to state that 25 cwts. of coke represented the effective working capacity of 12,000 cub. ft. of furnace: it should have been stated that the real capacity of 20,454 cub. ft. had been reduced to an effective capacity of only 7,800 cub. ft., the *loss* having been 12,654 cub. ft.

With regard to the diminution in pressure of blast at certain distances from the tuyeres, Mr. Bell seemed to question the accuracy of the figures given in the paper. He believed those figures and Mr. Bell's were both correct. Mr. Bell, having a larger quantity of

fuel to burn, had a more open furnace, and therefore greater facility for the rapid lowering of the blast pressure. He himself had found exactly the same state of things with a furnace 50 ft. high at Woodside, the pressure falling more than 1 lb. in a very short distance; whereas in the large Ormesby furnaces, in which there was less coke to be dealt with, the obstruction to the blast was greater, and the lowering of the pressure was much less rapid. As to the height of the slag in the centre of the hearth, Mr. Bell's remarks gave him an opportunity of making a slight addition, by no means in the way of correction, but in the way of enlargement, to what he had said. That the pressure of the blast was higher at the circumference of the hearth than at the centre was admitted by Mr. Bell himself; therefore the slag must stand higher under the lower pressure. This would be the case whether the furnace hearth were a closed one, or one of the open-hearth type. But Mr. Bell's point was this: that at the dam, over which the slag flowed away, the flow of slag ceased on the withdrawal of the blast pressure. In an open-hearth furnace this cessation of flow arose from the slag outside the hearth standing, under the lower pressure, in a column of sufficient height to counterbalance the total pressure of blast within the hearth; and as a matter of personal experience in past years with the open hearth, the slag would sometimes come back, when the blast was taken off, in such quantities as to flow into the tuyeres. Now in the system of closed hearth the fact remained that within the hearth the place of outflow of the slag was more remote from the tuyeres, as usually arranged, than was the centre of the hearth; so that what took place at the centre of the hearth would take place to a greater degree at the point of outflow, even in the closed-hearth system, and would so explain the falling away of the slag in this case also on the removal of the blast pressure.

Mr. Bell had also complained that the weekly make of the large Ormesby furnace was only 15 tons of pig per 1000 cub. ft. of furnace capacity, instead of 30 tons. But the difficulty of abstracting heat from the escaping gases of the furnace increased, the lower the temperature of those gases became; and therefore it was necessary to employ a much larger bulk of material in the upper regions of the furnace

than in the lower for abstracting an equal quantity of heat. The dead space, if he might so call it, which was employed for that duty, simply involved extra outlay in the shell of the furnace; and if $\frac{3}{4}$ cwt. or 1 cwt. of coke per ton of iron could be saved by a little more outlay, it was well worth while to make it. This had been found to be so at the large Ormesby furnaces, seeing that the coke consumption had there been brought down to $18\frac{3}{4}$ cwt. per ton of iron made.

Mr. Windsor Richards had alluded to the fact that the paper made no reference to the results with No. 3 furnace. He was sorry he had not given these, if the omission had been misleading in any way; but he had simply used No. 3 furnace to illustrate the bad work when the tuyeres were only 6 ft. apart. Since the withdrawal of the tuyeres to 7 ft. apart, No. 3 furnace had done similar work to No. 4, which had been described in the paper. Mr. Richards had also referred to the figures given by Mr. Jones, than whom there was no more careful furnace manager in the North of England; and the results obtained by raising his furnaces from 60 ft. to 75 ft. showed that the consumption of coke was thereby reduced by $2\frac{1}{2}$ cwt. per ton of iron, bringing it down from 24·95 cwt. to 22·45 cwt. But there was yet $3\frac{3}{4}$ cwt. more to save, in order to attain what was already attained by other furnaces; and this further economy could not be attained except by employing both higher temperatures and increased capacity of furnace. This brought him to his concluding observation, that, whereas some years ago capacity and high temperatures might have been deemed to be interchangeable—so that if the capacity were increased the temperature need not be increased, or *vice versâ*—it was now known that, at least up to the capacity of 33,000 cub. ft. and the temperature of 1400° or 1500° Fahr., better duty was obtained both for increased capacity and for increased temperature. To bring out this point had been a main object of his paper.

The President said he was sure the members would accord Mr. Cochrane a hearty vote of thanks for his paper. Some observations made during the discussion might lead them to suppose

that the paper was not one appropriate to their Institution: but he thought they would all agree with him in considering that anything bearing upon iron, particularly upon its production, was of direct interest to mechanical engineers. A paper of that kind, which had brought up men of eminence in their profession to give the benefit of their experience, must necessarily be of great advantage not only to themselves, but also to the whole engineering world.

ON MINING MACHINERY.

By Mr. HENRY DAVEY, of Leeds.

The object of the present paper is to notice improvements which have been made in machinery for mining purposes, and to discuss the salient requirements of Mining Machinery generally, with a view to discover the best direction for the further development of invention.

The requirements of coal and metalliferous mining differ; but the main features, as regards sinking, pumping, and winding, are the same: and it is to these operations that attention will be chiefly directed. The subject may be divided under the following heads:—

I. Shaft Sinking.
II. Pumping.
III. Winding.
IV. Underground Pumping.
V. Underground Hauling.
VI. Ventilation.
VII. Economical application of power to mining operations generally.

I. Shaft Sinking.

The site of the mine is usually determined, in coal and ironstone mining, by boring. There are two systems of boring, namely the percussive, and the rotative or diamond drill. The percussive system has several modifications, the most recent of which are described in a most valuable paper by M. Sarran, giving illustrations and a table of

results obtained at borings in the departments of Gard, Hérault, and Bouches du Rhône, in the south of France; and in a paper by M. V. Lecacheux, on sinking bore-holes in the Berry iron-ore district in the centre of France.*

As practical examples of the different machines used for boring with a free-falling tool, the author has reproduced from the above papers Figs. 1 to 6, Plates 59 and 60. These machines are clearly shown in the drawings; and it is unnecessary to describe them further than to give their general characteristics.

Figs. 1 and 2, Plate 59, show, in side and end elevation, the simplest form of boring tackle. It consists of a simple lever worked by hand. Triangular sheer-legs are erected over the bore-hole, and provided with a windlass for the purpose of drawing the rods.

Figs. 3 and 4, Plate 59, show the same kind of machine, worked by means of a direct-acting steam cylinder instead of by hand.

Figs. 5 and 6, Plate 60, show, in side and end elevation, a boring tackle provided with a steam-winch for raising and lowering the rods and tools; this is the most modern and best form of machine. The sheer-legs are 50 ft. high, and are provided with two stagings A and B for facility in handling the rods. The steam-winch is provided with a strong flat hemp rope C, going from the main drum D and over the top sheave, to lift or lower the boring rods; and a light round rope E going from a larger drum F over a lower sheave, to be used for the purpose of raising and lowering the clearing scoop. The actual jumping of the tool is done in the same way as in Fig. 3. With a speed for the driving pinion of 120 revolutions per minute, the velocities when running at high speed are 136 feet per minute for the scoop rope, and 132 for the rod rope; and when working at low speed, 20 feet per minute for the rod rope.

The diamond drill (see Proceedings Inst. M. E., 1875, p. 92) is specially useful for putting down trial bore-holes, as the boring

* See Minutes of Proceedings Inst. C.E., vol. lxvii., pp. 499–502; and vol. lxvi., pp. 436–439.

TABLE I.—BORINGS FOR IRONSTONE WITH THE DIAMOND DRILL.

No. of Boring.	Length of Time occupied.				Total depth of hole bored.	Average depth bored per hour.
	Total Time.	Lifting and Lowering Rods.	Other accessory work.	Actual Boring.		
No.	Hours.	Hours.	Hours.	Hours.	Feet.	Feet.
1	59¾	11¾	32½	15½	79	5·08
2	152	83½	43	25½	207	8·10
3	48	11	20½	16½	72	4·36
4	44	10½	17½	16	69	4·30

The size of each hole was 1·89 in. diameter throughout from top to bottom; and the average cost, including all contingencies, was 7*s*. 6*d*. per foot of depth.

TABLE II.—BORINGS FOR COAL WITH THE DIAMOND DRILL.

Locality of Boring.	Duration of Boring operations.	Time occupied in actual Boring.	Diameter of Borehole at Top and Bottom.	Total Depth of Borehole.	Average Daily progress.	Maximum Daily progress.	Total Length of Tubing inserted.
		Days.	Inches.	Feet.	Feet per day.	Feet.	Feet.
Bethlehem, near Liebau, Silesia.	15 Oct. 1875 to 19 Feb. 1876	68	7 and 3	1640	24·28	59·38	1467
Rheinfelden, Switzerland . .	14 Aug. 1875 to 15 Oct. 1875	34	7 and 3	1454	42·65	72·18	1210
Villefranche d'Allier, France .	28 Nov. 1875 to 4 Jan. 1877	145	9 and 3	2430	16·73	78·09	2298

The above are results of boring through strata composed of sandstone, shale, shaly clay, and conglomerate.

tool cuts an annular groove, and brings up solid cores of the strata passed through. In Tables I. and II. are statements by the Diamond Drill Company of work done in making trial borings for ironstone and for coal with this drill.

The diamond drill has also been proposed as a means for sinking shafts ; that is, to perforate the entire area of the shaft with holes bored to the full depth, then nearly fill up these holes with sand, insert dynamite above the sand, fire it, and remove the *débris :* then to repeat the operation by clearing out the sand to a certain depth, and inserting a fresh charge of explosive. The economy of this system was tested at the Von der Heydt Colliery near Saarbrücken; but it was found that sinking by hand in the usual way was much less costly.

The author has found it very difficult to ascertain the cost of boring in England. He has however obtained the following data, Table III., as to the cost of trial bore-holes for ironstone in the Barrow district, with steam-winch and free-falling tool, similar to Figs. 5 and 6, Plate 60, and passing through strata consisting of sand, shale, sandstone, and limestone.

The place for the shaft having been fixed on, the actual sinking may be done either on the old plan with pumping, or on the Kind-Chaudron system. The latter is intended for sinking through heavily watered strata without pumping; and has been resorted tc in cases where pumping has failed, such as the two shafts put down at Whitburn, near Tynemouth. A detailed description of this method was given in a paper read by Mr. Henry Simon before the Iron and Steel Institute in 1877 (p. 187). The plan consists briefly in boring the pit to the full size by means of a large free-falling boring-head, by which the rock is pounded to sand or mud, instead of being got in large lumps, as by blasting. It is evident therefore that the plan can only be economical in heavily watered pits, or where the cost of pumping would be excessive. A comparison of the cost of sinking on this system without pumps and on the old plan with pumping was given by Mr. Emerson Bainbridge in the Proceedings of the Institution of Civil Engineers for 1872 (vol. xxxiv., p. 58). This showed a very great advantage in favour of the Kind-Chaudron system in the cases mentioned.

Table III.—Cost of trial Bore-Holes for Iron Ore.

Depth of Hole.	Diameter of Hole.	Cost per Yard.		Cost of labour alone.			Time occupied.
Yards.	Inches.	s.	d.	£	s.	d.	Weeks.
126	6 to 2	7	10¼	49	10	0	15
124*	" "	9	7	59	8	0	18
50	" "	9	10¾	24	15	0	7½
63	" "	9	5	29	14	0	9
76½	" "	6	0½	23	2	0	7
88	" "	8	3	36	6	0	11
48	" "	11	0	26	8	0	8

* The strata passed through in this hole were as follows, proceeding from the surface downwards:—45 feet pinder, 75 red sand, 3 white sand, 30 red sand mixed with clay, 150 red sand, 30 red and white sand, 6 white sand, 6 shale, 4 ore, 6 clay, 1 ore, 2 stone, 9 ore, 2 black shale, 3 stone; total 372 feet.

II.—Pumping.

Where a large quantity of water is met with, and especially where the water-bearing strata extend to a great depth, it is of the first importance to fix generally the design and arrangement of the permanent pumping machinery before sinking is commenced. As to the extent to which the permanent machinery may be made available for sinking, there are different opinions; and the circumstances vary so much that no absolute rule can be laid down. Doubtless in many cases it is better to do the sinking entirely with temporary plant, especially when the quantity of water to be dealt with is unknown, and may be either large or small. But in metalliferous mining the permanent plant is often required almost from the beginning, as the sinking of the shaft and the working of the mine are necessarily proceeded with together.

The ordinary design and arrangement of pumps for sinking certainly need improvement; but improvement, if effected, will probably be adopted very slowly, because pumping in a shaft is at its best a critical operation, and can be carried out only by trained men, who are naturally reluctant to submit to a second training.

Bucket pumps are used in sinking, because of the liability of flooding to which the pumps are exposed from the sudden tapping of feeders of water; and it is a curious fact that in many districts bucket pumps are almost universal for permanent work also. In Cornwall however it has been the universal practice for the last thirty years to use nothing but plunger pumps for permanent work, except in the lowest lift of all. In a colliery, the quantity of water to be dealt with can generally be approximately calculated from local circumstances very early in the operation of sinking the pit; and if a temporary pumping engine be employed to begin with, the permanent one with plunger pumps may advantageously be put up during the progress of the work. The plunger pump may then be fixed temporarily, to take off from the buckets the excessive lift which would otherwise be thrown on them.

The system in use in Cornwall is to fix a plunger every 40 or 50 fathoms. For permanent work however, pumping in stages should be avoided, owing to the great attention needed, and the waste of power it entails; and while allowing a pair of plungers to work in stages during the sinking, the author would make each of them large enough to be fixed at the bottom of the pit on its completion, both of them delivering into the same rising column. By this arrangement the temporary engine would act the part of a pilot during the sinking.

The interruption which pumping causes to sinking, in heavily watered pits, is very serious. It is therefore important that new and more economical methods should be sought after. Messrs. Brown and Adams, in their recent paper before the Institution of Civil Engineers (Proceedings, vol. lxiv., p. 41), suggested putting down a boring in advance of the sinking, in which the sinking pumps could be placed. This seems a hint in the right direction; and it is a question whether it would not be an economical plan to bore a separate pumping pit—say half the size of the winding pit—on the Kind-Chaudron system, to the bottom of the water-bearing strata, and to fix the pumps in this before starting the main pit, which could then be put down in dry ground by the side of the pumping pit. This plan would involve putting down two pits; but two pits are necessary for the proper working and ventilation of a

colliery. The pumping pit might be made to serve also as the upcast shaft—a plan that is often adopted at the present time. A more economical plan still might probably be found in making a boring—say to a depth of 200 ft.—large enough to take a pump of sufficient size for raising the water, as in Fig. 7, Plate 61; and afterwards to put down a similar bore-hole after the 200 ft. level had been reached.

There are several methods of dealing with pumps during sinking operations.

1st. To fix the rising main or pump trees as the work proceeds, and add pipes above the working barrel as the shaft is deepened. This plan involves a telescopic or flexible suction-pipe, or a telescopic pipe above the working barrel. With twin pumps, as in Fig. 8, Plate 61, this is a good plan, because one pump can be kept going whilst pipes are added, or whilst a bucket is changed in the other.

2nd. To sling the pumps by ground spears or wire ropes, as in Fig. 9, Plate 61, and add pipes at the top of the lift.

3rd. To use a pilot bucket-pump, and fix plungers every 40 or 45 fathoms, as is done in the Cornish mines, Fig. 10, Plate 62.

4th. To use a pilot bucket-pump worked by an independent engine, and fix plunger pumps every 40 or 45 fathoms until the bottom is reached; and then to fix plungers permanently at the bottom, for the whole height of lift.

All these plans involve frequent alteration in the balance of the engine, causing considerable trouble and loss of time. The author has accordingly introduced into his own pumping engines a means of giving a different supply of steam to the two ends of the low-pressure cylinder, thus enabling the engine to be worked out of balance during sinking. The device consists simply of a shutter at the back of the low-pressure slide-valve, Fig. 11, Plate 60, with means of adjustment outside the valve-chest. By shifting the shutter over the forward or backward port of the slide-valve, either one or the other may be throttled to suit the want of balance in the load on the engine.

Pumping engines employed in sinking are subject not only to loss of load from breaking of spears &c., but also to a "riding column,"

when a foot-valve breaks or fails to shut, whereby the load on the engine is reversed so as to act in conjunction with the steam-pressure instead of opposing it. No amount of governing on the admission side of the piston is equal to such a contingency. The governing action of the main gear is sufficient, where there is not a great mass in motion to accumulate momentum; but it is often not equal to bringing to rest, within the limits of the stroke, a great mass moving under the exceptional condition above described.

The author has devised a means by which, whenever the engine suddenly increases its speed during the stroke, communication between the high and low-pressure cylinders is suddenly closed, thereby not only stopping the admission to the low-pressure cylinder, but also cushioning the steam in front of the high-pressure piston.

This retarding apparatus is illustrated in Figs. 12 to 14, Plate 63. It consists of a lever A, one end of which is attached to a moving part of the engine, while the opposite end is made to actuate the trip B of a double-beat valve C, closing the communication between the high and low-pressure cylinders. To the centre of the lever A is attached a subsidiary piston D, working in a cylinder filled with water. The end of the lever which actuates the trip is held stationary by means of two springs E E, so arranged as to oppose each other. The engine in working gives the engine-end of the lever a reciprocating motion, and thereby causes it to reciprocate the subsidiary piston in the water cylinder: but the motion of this piston is resisted by means of a conical plug F throttling the passage that communicates between the two ends of the water cylinder. When the engine is working at its normal speed, the conical plug is screwed up until the resistance thereby opposed to the subsidiary piston causes the trip end of the lever to partake of a slight reciprocation, and to be just on the point of tripping the valve. When working under this condition, should the engine happen from any cause to make a quicker movement, the resistance in the water cylinder would be increased, the valve would be instantly tripped, and thereby the admission would be cut off from the low-pressure cylinder, and the steam cushioned in front of the high-pressure piston.

III.—Winding.

Coal mining, as requiring very large out-puts, involves the use of direct-acting engines for quick winding; whilst for metalliferous mining geared engines give sufficient speed, and are more commonly used. With geared winding engines, the load in the shaft travels so slowly, that its inertia, momentum, and speed do not practically interfere with the application of ordinary methods of expansive working. Few direct-acting winding engines work expansively, although several expansion gears have been brought out from time to time. Of these, all which require special attention from the engine-driver, who is sufficiently occupied with the simple reversing lever, have fallen into disuse; whilst those requiring no more manipulation than that given by the reversing handle are gaining in favour.

A very excellent expansion gear, illustrated in Figs. 15 and 16, Plate 62, has come under the author's notice in Germany. The valves are lifted by cams, the expansion cams AA being shaped after the manner of the old stepped cam, but with the steps made so numerous as to form a continuous curve, thereby rendering it possible to shift the cam longitudinally under the lifter B. The cams are so made and arranged as to perform the functions of a reversing and expansion gear, by the simple movement of the reversing handle. Other forms of expansion gear are in use, some having a trip on the spindle of the steam valve.

The chief modern improvements and changes in direct-acting winding engines are as follows:—

1st. Expansive working;

2nd. The counterbalancing of the rope by means of a conical drum, and also by means of a tail rope suspended under the cages;

3rd. The short-rope system,* in which the rope makes rather more than half a turn round a single large driving pulley, instead of a number of coils round a drum;

4th. The application of separate condensing engines.

Direct winding is done at enormous speeds, as will be seen from the following example. At the Bestwood Colliery, near Nottingham, a pair of direct-acting winding engines, with cylinders

* See Proceedings Inst. C.E., vol. lvii., p. 407.

36 in. diameter and 6 ft. stroke, are employed in raising coal from a depth of 1300 ft. One complete run, including changing, is made in 55 seconds. The weight of coal raised each time is 2 tons 2 cwt. Therefore this engine is capable of raising 1150 tons in $8\frac{1}{2}$ hours from the depth of 1300 ft. The average speed of the cages while running is 22 miles per hour, and the maximum about 35 miles per hour.

IV.—Underground Pumping.

Pumping under ground may be done by steam, by compressed air, or by water-pressure. Compressed air, though very convenient, is not very efficient. It is usual to employ an air-pressure of from 40 to 45 lbs. per sq. in., at which the efficiency is about 25 to 33 per cent. of the power expended in compressing the air. Hydraulic engines give an efficiency of from 50 to 60 per cent.; but if the power producing the water-pressure is applied at the surface, the absolute pressures below become very great, whilst the available pressure is only that produced at the surface, since the descending and ascending columns balance each other. Where the main pumps are large enough to supply the water required for the underground machinery, then hydraulic power is by far the best.

There are many examples of large hydraulic engines placed underground, but actuated from the surface, and employed in pumping; notably the engines put up on the Comstock Lode by Mr. Joseph Moore of San Francisco; also five large engines put up by the author's firm for draining the Mansfeld Salt Mines in Westphalia.* The sixth engine for these mines is now to be seen at the Sun Foundry, Leeds, in the course of construction. This engine has 15 in. power and 16 in. pump rams, each with 6 ft. stroke.

Mr. Joseph Moore, who has had very large experience with pumping machinery in the county of Nevada, California, where the mines are probably the deepest in the world, has kindly sent to the author the following notes of his experience.

"The type of engine first used was the horizontal geared engine, made to actuate the pumps by means of quadrants. As the mines

* See Proceedings Inst. M.E., 1880, pp. 251–2.

became deeper, the geared engine was replaced by the compound direct-acting engine. A few were made with fly-wheels, but the pumping capacity did not come up to what was expected. The slightest increase of speed over six revolutions per minute would cause a break-down. In the Yellow Jacket mine, both fly-wheels had the arms jerked out of the wheel, and the whole of the rims and arms fell on the top of the machinery. Again, the engines could not go slower than three revolutions per minute; so that, when water was short, part of the water pumped had to be allowed to run back to the bottom of the mine. The engine that has done the best work of any on the mines is a compound direct-acting non-rotative engine, of the "differential" type. It is working 14 in. pumps, with perpendicular spears to a depth of 1200 ft.; the spears then going off down an incline, and reaching to a depth of 3200 ft. from surface. The total length of pump-rods is over a mile. This engine has kept steadily at work, making as much as six double strokes per minute, without any mishap, except a spear-rod breaking now and then." *

The difficulty of keeping spear-rods free from breakages, when of such enormous lengths and carried to such great depths, induced Mr. Moore to propose a hydraulic system for the Savage shaft. His plans were carried out; and from notes which he has kindly sent, the author has been able to prepare the following brief description of the plant. The system consists of a compound differential pumping engine at surface, with 35 and 70 in. cylinders of 10 ft. stroke, working four $8\frac{1}{2}$ in. plunger pumps, which deliver into an air-vessel, whence a supply pipe is taken down to a pair of hydraulic pumping engines at the bottom of the mine. These engines are employed in pumping up direct to the Sutro tunnel, against a head of 813 ft. or 352 lbs. per sq. in. The exhaust water from the hydraulic engines is delivered to the surface. The several pressures and depths are as follows:—initial steam-pressure, 80 lbs. per sq. in.; pressure in air-vessels, 960 lbs. per sq. in., or 2220 ft. head of water; depth of hydraulic pumping engines below ground, 2413 ft.; depth of Sutro tunnel below ground, 1600 ft.; height of lift from pumps to Sutro

* The above figures have been already given by Mr. Moore in a paper before the Institution of Engineers and Shipbuilders in Scotland, on 21st March, 1882.

tunnel, 813 ft. The hydraulic pumping engines underground are each provided with four $6\frac{1}{2}$ in. power plungers of 10 ft. stroke: and each pair of power plungers in turn carries a 14-in. pump-plunger, for forcing water up through the 813 ft. from the bottom of the mine to the Sutro tunnel. It is therefore seen that the efficiency developed by the hydraulic pumping engines, in actual water pumped up through the 813 ft. height, in comparison with the power water consumed in them, amounts to 85 per cent.; whilst according to the pressure gauges the friction of the engines is from 12 to 15 per cent., including the friction of the supply and exhaust water columns, each 2413 ft. in height. The pumps raise from 1600 to 1700 gallons per minute.

V.—Underground Hauling.

Hauling may be done on any one of four systems:—by the use of a tail rope, an endless chain, an endless rope, or compressed-air locomotives.

In 1867 a committee of the North of England Institute of Mining Engineers * made a careful investigation into the first three of these systems of hauling, as then in use. The following Table IV. gives a summary of their results.

Table IV.—Cost of Underground Haulage.

System of Haulage.	Average Gradient for Full Tubs.	Cost in pence per ton per mile.							
		Ropes or Chains.	Tubs.	Grease and Oil.	Coals.	Repairs to Engines and Boilers.	Maintenance of Way.	Labour.	Total.
Tail Rope	Rise 1 in 213	0·276	0·114	0·186	0·558	0·098	0·064	0·583	**1·879**
Endless Chain	Rise 1 in 59	0·083	0·173	0·155	0·256	0·072	0·068	0·572	**1·379**
Endless Rope	Rise 1 in 36	0·252	0·309	0·138	0·323	0·196	0·083	1·692	**2·993**

The endless chain is largely used in the Burnley district, and has lately had important applications in the North of England.

* See their Transactions, vol. xvii., 1867–8, p. 144.

The motive power required for hauling may be economically provided by having duplicate pumping plant, and using the second plant for supplying the hydraulic power required for the hauling. This plant would then serve the additional purpose of being available for pumping, on the emergency of an accident with the main engine. The efficiency of hauling engines working under such conditions would be from 50 to 60 per cent. of the power applied in the pumping engine; and as it is practicable to work pumping engines much more expansively than air-compressing engines, there is a considerable gain in that respect also. The efficiency of the two systems may be taken as follows:—Compressed air, 25 to 33 per cent.; Water pressure, 50 to 60 per cent.

VI.—Ventilation.

The old furnace system of ventilation is rapidly becoming a thing of the past, mechanical ventilation having proved itself much more economical.

A Committee of the North of England Institute of Mining Engineers, of which Committee the author was a member, has lately made an exhaustive investigation as to the efficiencies of different kinds of mechanical ventilators now in use; and the following Table V., p. 332, is a summary of the results obtained.*

For a comparison between the efficiency of furnace and mechanical ventilation, a portion is here reproduced (Table VI.) of a Table of the duty of furnace ventilation, from Mr. William Cochrane's paper read before this Institution in 1869 (Proceedings 1869, p. 136).

VII.—Economical Application of Power.

Electricity in now becoming recognised as a practical method of transmitting power; and as the same appliances which may be used for that mode of transmitting power may also be used for producing light, there seems a future in mining operations for the utilisation of this form of energy. It is possible that the mechanical operations

* See their Transactions, vol. xxx., 1880-1, pp. 288-290.

Table V.—Efficiencies of Mechanical Ventilators.

No.	Name of Ventilator.	Dimensions of Ventilator.					Dimensions of Engines.				General Results.		
		Diameter.	Width, &c.	Theoretical Displacement per minute.	Diameter of Inlet.	Weight.	No. of Cyls.	Dia. of Cyls.	Length of Stroke.	Direct-acting or geared.	Volume of Air per minute.	Mean Water Gauge at Drift Door.	Percentage of Useful Effect.
		Ft. In.	Ft. In.	Cub. Ft.	Ft. In.	Tons.	No.	In.	Ft. In.		Cub. Ft.	Inches.	Per cent.
1	Guibal	Fan 50 0	12 0		15 0	50	1	42	3 6	Direct	108,422	3·30	40·00
2	Do.	,, 46 0	14 10		13 0		1	36	3 6	Direct	246,509	1·85	52·95
3	Do.	,, 40 0	12 0		14 0	24	1	36	3 0	Direct	170,581	1·46	47·95
4	Waddle	,, 45 0	Inlet 6 6 Periphery 1 5		15 0		1	32	4 0	Direct	163,312	3·08	52·79
5	Schiele	,, 12 0	2 1				1	25	2 0	2·57 to 1	157,176	1·91	46·12
6	Do.	,, 9 6	Inlet 3 2 Periphery 1 8		8 0		1	20	1 8	$2\frac{1}{2}$ to 1	106,570	2·03	49·27
7	Lemielle	Chamber 22 6 Drum 15 0	Height 32 0	9·9 rev. 108,900			1	55	6 0	Direct	47,307	1·37	23·40
8	Struvé	2 Pistons 18 3	Stroke 7 0	$6\frac{1}{2}$ rev. 47,827			1	24	4 $4\frac{1}{2}$	4 to 1	43,793	5·11	57·80
9	Nixon	2 Pistons, 30 ft. long, 20 ft. high	Stroke 7 0	7·19 rev. 120,790			1	36	6 0	Direct	72,595	2·74	45·91
10	Root	2 Drums 25 0	13 0	16·71 rev. 96,918			2	28	4 0	Direct	89,772	3·29	47·84
11	Cooke	2 Drums 15 0 Casing 22 0	11 6	17·92 rev. 80,640			1	25	3 6	Direct	54,190	1·12	37·33
12	Goffint	2 Pistons 13 2	Stroke 10 $7\frac{3}{4}$	$9\frac{1}{4}$ rev. 53,020			2	$15\frac{3}{4}$	10 $7\frac{3}{4}$	Direct	36,286	0·71	25·79

TABLE VI.—DUTY OF FURNACES AT THREE COLLIERIES IN THE NORTHUMBERLAND AND DURHAM COALFIELD.

Name of Colliery.	Downcast Shaft.		Upcast Shaft.		Area of Furnace Grate.	Temperature of Air.						Volume of Air circulated per minute.	Water Gauge in the Mine.	Coal consumed in 12 hours.	Consumption of Coal per hour per H.P. in the air.
	Diam.	Depth.	Diam.	Depth.		Top of Downcast.	Bottom of Downcast.	Return air near Furnace.	Bottom of Upcast.	Half-way in Upcast.	Top of Upcast.				
	Feet.	*Yards.*	*Feet.*	*Yards.*	*Sq. Ft.*	*Fahr.*	*Fahr.*	*Fahr.*	*Fahr.*	*Fahr.*	*Fahr.*	*Cub. Ft.*	*Inches.*	*Cwts.*	*Lbs.*
Rugeley	12	160	12	160	64	...	...	61	141	117	110	103,325	0·62	40	37·0
North Seaton	15½	250	9	266	72	68	70	65	225	206	186	99,750	1·10	91	49·2
Ryhope	15	508	10½	460	160	62	...	76	170	...	134	126,366	1·00	120	56·3

underground requiring small powers, together with the lighting, may be done eventually by means of electricity transmitted from a dynamo machine worked on the surface. From the same source the pit top may be lighted. This idea leads to a consideration of the source from which the power is or may be derived. Electricity as a transmitter of energy is economically practicable; but as a source of power or prime mover there is little likelihood of its competing with coal. Heat in steam, gas, or air engines, must be looked to as the source of power, except in districts where water-pressure is available; but it is in these latter districts that there is a field for electric transmission. Water-pressure is often available in metalliferous mining districts, either at the mine or at some distance from it. When at a distance, the power may be developed by means of water-wheels, turbines, or water-pressure engines; may be transmitted by electricity to the mine; and may there be made available for driving the machinery. But these cases are exceptional; and for economy in the production of power in mines generally, the author would direct attention to the results which have been obtained with gas engines; and would venture to predict that the gas engine, or rather the hot-air engine worked by the quick combustion of gas, is likely to play an important part in mining as well as in other spheres of industry. From present experience it is perhaps not visionary to suppose that the time is not far distant when tall chimneys will cease to pour blackness over our towns and country; and when coal, still continuing to be the chief source of power, will be completely consumed in the shape of gas, or burnt direct under pressure. Modern experience points to the hot-air or gas engine as the prime mover, and to electricity as the transmitter of power, in the future.

APPENDIX.

ON SHAFT-SINKING IN THE WESTPHALIAN DISTRICT.

By Messrs. W. T. MULVANY and T. R. MULVANY, of Düsseldorf.

The small dimensions, irregular forms, and temporary modes of fitting up shafts, which were used in former times in Great Britain, and are still practised in some other countries, with much danger to human life, are no longer applicable, or indeed permissible, in the circumstances of the increased depth of mines, their increased measure of production, and the general wants and progress of the present age.

The scope of the present paper is limited to the technical questions of the best system of Shaft Sinking in different strata, under the condition of the presence or absence of water; and of the means of contending with the water where present in large quantities.

The writers' personal experience has been attained in sinking ten coal shafts within the last twenty-seven years, in the virgin soil of Westphalia (where the coal formation is covered deeply with the "Kreide" or chalk formation), and also some iron-mine shafts in different parts of Germany; whilst during the same time they have had the opportunity of observing other shaft-sinking operations, not only in Germany, but also in England and parts of Scotland.

The execution of the works in these ten shafts, between March 1855 and December 1876, combined with the fact that in the greatest and most difficult part of them the writers were thrown on their own resources and responsibility, in a foreign country, where they had personally to watch over and provide for every detail, afforded them special opportunities of gaining experience as to the water-bearing measures of the chalk or marl formation, and the underlying coal measures of Westphalia; and this experience they have much pleasure in placing at the disposal of the Institution.

THE "KREIDE" OR CHALK FORMATION OF WESTPHALIA.

The great coal district of the Rhine and Westphalia lies for the most part in a comparatively flat country, stretching along the valleys of the rivers Ruhr and Emscher. These rivers fall into the Rhine from the east at Duisburg and Ruhrort respectively. Along the Ruhr the coal formation, which to the southward overlies the millstone grit and carboniferous limestone, crops out to the surface; whereas along the river Emscher, as far as Dortmund and Hamm, it is deeply covered with the chalk or marl formation. This latter district lies low, being in the centre about 200 feet above the level of the sea.

The coal formation, which contains more than sixty workable seams of coal, besides numerous smaller ones, lies in undulating curves, created by former up-heavings of the strata, as shown in Fig. 17, Plate 64. It has a tolerably regular surface, falling from the south to the north at about one in fifty, and with a much less inclination from the middle of the district towards the east.

The chalk, locally called "Mergel" or marl, was evidently deposited subsequently to the settlement of the coal formation, and lies unconformably upon it, in horizontal stratifications. Its southern boundary is well known, and distinctly marked on the maps, stretching in an east and west line between the Ruhr and Emscher valleys, and for a considerable part of the distance following closely the water-shed line between these rivers. Along this line it is very thin, only a few feet in thickness, and is broken up in its stratification, while in all cases its bottom along this boundary is above the sea-level. To the north however, owing to the above-mentioned fall or dip in the coal formation, the marl has been proved to a depth of more than 680 feet below the level of the sea; and it attains a thickness in many places of over a thousand feet.

In this chalk formation, the upper chalk with its flints, so far as the writers know, is wanting; and whilst the upper and lower greensand are invariably present, the stratum between these, called "Gault" in England, is here represented by a very white argillaceous chalk or marl. Underneath the lower greensand there is almost invariably a

thin bed of small gravel, indurated into a concrete, and containing 12 per cent. to 18 per cent. of iron ore. This is called in German "Bohn-erz" or bean-ore, and serves admirably, by reason of its density and structure, to shut off from the coal measures below the water contained in the marl formation above.

The above succession of strata the writers have found to occur almost invariably in the shafts and numerous bore-holes sunk by them. The strata with their respective thicknesses are shown on the sections of the shafts, Figs. 18, 26, and 27, Plates 65 and 66.

From a geological point of view it is interesting to remark that in this case the chalk or marl formation is laid directly on the coal measures; and that all the intervening formations—the Wealden, Oolitic, Liassic, Triassic, and Permian—found either in whole or in part in Great Britain and other countries, are here wanting.

The writers have stated the above geological particulars of this formation, as now known to them, in order to make more clearly intelligible the subsequent remarks on the system of shaft-sinking in this district. As a general result of their experience, much less water has been found in the marl formation in the western part of the district than in the eastern; which may perhaps be attributed to the higher level of the country at the southern outcrop of the chalk formation in the western part, whilst in the eastern the outcrop is crossed by rivers and small streams, which, as the writers' local observations lead them to believe, deliver much more of their water than is generally supposed into the open clefts and fissures of the chalk marl at and near its outcrop.

Be this as it may, the fact is indisputable that the eastern part of the district, notwithstanding the greater thickness and consequent weight and density of the chalk, is far more filled with water, over the coal measures, than the western.

The general result of the writers' experience, both in boring operations and shaft-sinking, has been to prove, that this chalk formation is traversed, in various directions and at various levels, by fissures and clefts, some horizontal, some oblique, and some vertical, or nearly so; others syphon-like; and mostly connected with each other. These are without any large cavernous openings, such

as are common in mountain limestone; but, through their free communication with each other and their ample sources of supply, they are capable of delivering very large quantities of water per minute, as hereinafter shown.

In some cases the writers have found the water-bearing fissures in the upper part of the grey marl; in others the upper and middle parts were quite dry, and the water-bearing fissures were in the lower part of the marl, at a depth of several hundred feet. In some cases they have found the water-supplies cut off by the change of strata at the greensand; in others the water has continued through the greensand down nearly to the "bohn-erz," or conglomerate iron ore, which, as above stated, almost invariably separates the chalk from the coal formation.

In recent years, since the writers' success in overcoming the great feeders of water in the "Hansa" and "Zollern" shafts, in the eastern part of the district—which had been abandoned by German companies as impossible to complete,—many other shafts have been sunk through the marl in the same neighbourhood, and have had to contend, strange to say, with comparatively small feeders of water; whilst in other cases feeders met with at many miles' distance have been proved beyond doubt to be connected with those in the marl at Hansa and Zollern. Again, large feeders of water met with in the workings of mines at very considerable distances have proved to be connected with the same marl feeders, and with each other; showing beyond a doubt the necessity of adopting, for the common benefit, a general system of stopping or cutting off the water-supplies, and of pumping the marl water out of this enormously rich and extensive coal field. At present some collieries are so encumbered with water as to have very great difficulty in working; and other collieries and new winnings have been altogether drowned out for want of such a system.

In the western part of this coal district the water feeders have not increased in volume; on the contrary, in the shafts constructed by the writers, and in which they are interested, the quantity has sensibly diminished after more than twenty-five years' coal working, and further sinking of the shafts to lower beds of coal.

When the writers commenced operations in 1855, the condition of the overlying strata was but little known in the district, and still less to themselves; but in every case, before commencing to sink a shaft, they took the precaution to have borings carefully made under their own inspection, and by a first-rate bore-master, near the site of the intended shaft. These were in addition to the borings already made to prove the coal, and to obtain the coal concession or grant from the State.

By this means the writers ascertained and noted on sections the nature and position of the strata, down to the coal measures, and with great care endeavoured to ascertain the presence and position of water-bearing fissures in the marl formation. This information served to guide them in making arrangements, and in providing materials and machinery for the shaft-sinking operations. Of course borings are, as a general rule, only useful in detecting horizontal fissures, as they might pass close down beside a vertical fissure without giving any indication thereof: and they only prove the presence or whereabouts of water; they cannot indicate its quantity.

In concluding this general description of the chalk, it may be remarked that above this formation the writers have found in general, after sinking through the surface-clay or alluvium, a more or less thick stratum of quicksand, containing in some instances boulders of granite. These boulders must have come in the glacial period from Sweden or Norway. Some fossil remains of much interest have been found in this stratum of quicksand.

Shaft-Sinking.

The ten shafts referred to above have been sunk for five large collieries, in that part of the coal district which is covered with the chalk formation. Six of these are in the concessions of the "Hibernia," "Shamrock," and "Erin" collieries; and the other four in two large concessions, formerly the property of the Hansa and Zollern Colliery Companies. In each of the latter cases shafts had already been sunk into the marl; but the quantity of water being larger than could be contended with by the system adopted, they had been abandoned.

Before the writers commenced the sinking of the "Hibernia"

shafts in March 1855, but few shafts had been sunk, or attempted to be sunk, in the chalk; and those chiefly in the shallow marl in the western part of the district, where the quantity of water was comparatively small. The system followed up to that time by the Germans, in such cases, was to sink through the quicksands, and the "Thon-mergel," or soft marl lying over the solid marl, by means of a sink wall built on a wooden or iron crib-shoe; and then to sink the shaft down to the stone head, where they laid a foundation, and then walled the shaft up to bank with bricks, hydraulic lime and "trass" mortar. In cases where feeders were large, they sought to make a foundation in the marl itself for the walling, which, in order to shut off the water, was built in that case of great thickness. It is hardly necessary to mention that this very expensive, and at the same time very slow system, was only partially successful, even in cases of moderate depth, and with comparatively small feeders of water.

In the year 1852, at Dahlbusch Colliery, a shaft of 3·50 m. (11ft. 6in.) diam. was commenced to be bored down by the Kind-Chaudron system, in marl 364 ft. deep. It reached the stone head in 1854; but owing to the system of wooden "cuvelage," or casing, adopted to shut off the water, it was not completed or brought into use until a considerable time after coal-getting had been commenced, and coal sold in large quantities, from the Hibernia colliery, although here the operations were not commenced till 1855.

At the Hibernia and all the other shafts of the writers' collieries, they adopted the English system of sinking and pumping; hanging and guiding the pumps with ground-spears and crabs, and using cast-iron wedging-cribs and tubbing, to make the shafts water-tight.

HIBERNIA COLLIERY.

This colliery is situated at Gelsenkirchen, and has a royalty of 500 acres. The thickness of the marl from the surface to the coal formation (which lies at 246 feet under the level of the sea) is 387 feet. The sinking of the shafts was commenced in 1855, No. I. being 12 feet diameter, and No. II. 10 feet. The preliminary borings had indicated the site of water-bearing fissures, subsequently proved in sinking. No. I. shaft was sunk very rapidly, and

without any difficulty worthy of note; and the water-feeders, amounting to about 120 cub. ft. per minute, were successfully tubbed back. The water was pumped with 18-in. sets, by a horizontal engine with spur-wheel pumping-gear, the latter giving much trouble. The shaft was sunk to a depth of 696 feet from the surface, into the coal measures; and within about eighteen months from commencement of sinking coalwork was started. Within a short time a production of 600 to 700 tons per day was reached; more than double that of old-established collieries in the district. Since then the two shafts have been sunk to a depth of 1149 feet, and the production brought up to 1100 or 1200 tons per day. The quantity of water in the mine, which is pumped by the main engine at bank, is only 5 cub. ft. per minute.

Shamrock Colliery.

This colliery is near Herne, and has 1500 acres royalty. The depth of marl from surface to stone head or coal formation is 503 feet; the surface of the coal formation being 279 feet below sea-level. There are two shafts: No. I. a winding and pumping and downcast shaft 13 feet diam.; No. II. a winding and upcast shaft 10 feet diam., with furnace. No. I. was commenced in 1857, and was ready for coalwork in about 18 or 20 months.

No. II. shaft was commenced in 1862. The preliminary bore-hole in this case indicated that, after passing through the surface measures and quicksands, water would be found in the upper marl to a depth of about 20 fathoms or 120 feet; and that below such depth the marl was dry. On sinking, this proved quite correct.

The writers had some difficulty with the quicksand, on attempting to drain it by an open drain into an adjacent valley, in order to procure solid foundations for engines, chimney, &c. Finally they adopted for the shaft the German system of a sink wall 20 in. thick, with iron shoe attached to wooden cribs; by which means the shaft was sunk into the "Thon-mergel," or upper marl, at a depth of about 26 or 28 feet.

The foundations for the high chimney, engine, boiler, &c., were simply built on broad solid masonry platforms—with the excellent

German hydraulic mortar — upon the quicksand, and they have remained perfect without a shake to this day.

The sinking was proceeded with through the water-bearing marl to a depth of about 126 feet, the quantity of water not being excessive. About 60 cub. ft. per minute was pumped with 18-in. sinking sets and ground spears, by a twin horizontal winding engine and spur gear. The water was completely tubbed off with English cast-iron tubbing. From this point to the coal measures, and down to the first working level or gallery, at 876 feet, the shaft was sunk very rapidly without any pumps whatever. Below the tubbing the shaft was walled in, at convenient lifts of 10 to 12 fathoms, with 10-in. to 15-in. brick walling set in hydraulic lime.

From time to time since then, the shafts have been sunk further through the coal measures, and have now, in 1882, reached a depth of 1542 feet; and the total quantity of water now pumped (being all mine water) is only $17\frac{1}{2}$ cub. ft. per minute, though a very large extent of colliery is now opened out and in work, producing 1,200 to 1,400 tons per day, after being worked for more than twenty-four years.

Erin Colliery.

This colliery, containing 2,500 acres, is near Castrop; the thickness of the marl from the surface to the coal measures, which lie at 417 feet under sea-level, is 656 feet. The strata sunk through are shown in Fig. 17, Plate 64, as are also the various seams of coal met with in the coal measures.

The sinking of the two shafts (47 feet apart) was commenced in July and August 1866; and applying the experience they had acquired up to that time, the writers constructed these shafts of a net diameter of 14 ft. 5 in. each. The shafts were sunk with sink walls through the surface soil, quicksands, and upper soft marl, to the depth of about 50 feet; and of such an increased diameter as to allow of tubbing, finished off with walling towards the surface, being carried up inside to the net diameter of the shaft. The preliminary boring indicated water in the upper marl to about 160 or 170 feet depth, whilst from thence downwards, as at Shamrock, the

marl was quite dry. Preparations were made accordingly, and water feeders were met with, which proved not inconsiderable. They were evidently to a great extent surface water, many wells in the immediate neighbourhood being dried. This water, amounting to some 70 or 80 cub. ft. per minute, was pumped, and completely tubbed off at 171 ft. 6 in. from the surface. Great facilities in dealing with this water, which was pumped with 18-in. sets and comparatively light engines, were found to be given by the contiguity of the two shafts.

The pumps having been removed, the two shafts were rapidly sunk, and were secured in convenient lifts, by bull-head brick walling, down to and into the coal measures, by December 1868; when shaft No. I. had reached the depth of 1160 feet, and shaft No. II. the depth of 810 feet below the surface. The marl proved very strong, with close partings, but perfectly dry all the way, and had to be blasted throughout. Only manual labour was used in drilling the rock, &c., mixed gangs of English and German sinkers being employed at daily wages; and the progress made was about 89 feet sunk and securely walled per month.

These were the circumstances of sinking; and what is still more remarkable, the colliery was worked for three years without pumps in the shaft, though the pumping engine (a double-acting main beam engine) was erected in its place. Up to that time the stone drifting and coal workings yielded no water; but then, in working coal in some seams lying at a very steep angle, at about 440 yards north-east of the shaft, and at a depth of 76 feet under the marl formation, some water from the marl began to show itself: and then at last the permanent 18-inch forcing sets were built in, with a short lifting set from the sump up to the lowest forcing set; the total depth to sump level being 1,160 feet. The coalwork was discontinued at the place where the water came off; and no further increase of water occurring north of the shafts, this pumping system for a time proved sufficient. Later on, feeders were met with to the south of the colliery; and meanwhile, having obtained railway connection, the colliery was extensively opened out, and the production of coal brought up to from 700 to 900 tons per day.

The gradual increase of water, and the writers' experience of sinking at Hansa and Zollern Collieries, in the eastern part of the district, and of coalwork at the former, warned them to provide additional pumping power at Erin; and preparations were made for the erection of two powerful underground pumping engines, constructed by Messrs. Hathorn & Davey, Leeds, on the site shown at E in Fig. 17, Plate 64, being 900 feet from the surface. Both engines were designed to force through one rising main direct to the top.

One of these engines was at work, and the second in course of erection, when suddenly, and quite unexpectedly, on 3rd September, 1875, a great feeder of water broke away in the "Tom" seam towards the south west—a seam which till then had given little or no water. This was at a depth of 800 feet from the surface, and 190 feet under the bottom of the marl formation; the water rose out of the floor of the seam, both floor and roof standing well at the time. The feeder delivered at first a quantity of water measured to be 1,200 cub. ft. per minute; however during the time it had free vent it diminished to 1,000 cub. ft., and even down to 600 or 500. It would no doubt have run off eventually to a still greater extent; but not having surplus pumping power at command, the writers were obliged to go to work at once and dam it off. This was done in a short time with complete success by dams AA, Fig. 17, Plate 64, built of brick and cement in the solid sandstone of the stone drifts, in the 116 Lachter and 108 Lachter levels.*

Fortunately, precautionary measures had previously been taken to guard against sudden increase of water, or break-downs of pumps or engines, by placing a dam at a lower level, and so providing considerable storage. This provision, with the then available pumping power, and water-winding power, allowed time to complete the dams AA in question, which were well let into the solid stone of the roof, sides, and floor of the drift, and were well splayed out against the direction of pressure. The brick-work was laid in an arched form, and resisted the immense pressure (some 25 to 26 atmospheres) with complete success. The entire feeder was dammed off by the end of the

* A Lachter is a German measure, equal to 6 ft. 10 in.

month of September, during which month a second inundation had taken place by the breakage of a delivery pipe at the bottom of the dam. This however was effectually plugged off (there being then still storage to spare), and thus the colliery was saved from inundation.

Now it is worthy of note that this occurred at a place, not only so deep under the bottom of the water-bearing measures, but over 700 yards from the shafts; these having been sunk, as described, for the greater part perfectly dry, and the colliery worked for about three years without pumps.

The coalwork of the colliery was continued in other seams. But the "Tom" seam yielding a clean coal, excellent in quality, and being of good working thickness and therefore of great value, a cross-cut or stone drift was led into it at another point, about 600 yards eastward of the point of influx of the great feeder, and to the east of a small fault, which throws this seam to the north some 180 feet. The seam here proved dry, and was opened out to a considerable extent with great success up to the end of 1876. Subsequently, in April 1877, after the writers' connection with the colliery had ceased, when working the broken coal in this seam, a second inburst of water took place at about the same level, but at a point some 900 yards to the eastward. This feeder, when it broke out, was also about 1200 cub. ft.; but while dams were being constructed it diminished to 600 cub. ft., and subsequently to 300 cub. ft. per minute. It is now no doubt less, as other collieries are pumping from the same source. Dams were erected at points BB, Fig. 17, Plate 64, and completed by 2nd May, 1877; but being in an unfavourable position they failed to shut off the water effectually, and this great and valuable colliery, with one of the best sections of coal seams in the country—which could easily be brought up to a production of over 2000 tons a day—was completely inundated. The water is proved, by observation in neighbouring collieries and in sinking shafts, to be from the marl.

In sinking the shafts at the adjoining collieries of "Graf Schwerin" and "Victor," water was also met with only in the upper marl; but both of these collieries, at a period subsequent to the inundation at "Erin," met with very heavy feeders of water at still

greater depths in the coal measures. Their direct connection with the Erin feeders is proved by the effect on the level of water in the shaft at the last-named colliery, which has sunk from 26 to 99 feet below the surface. Graf Schwerin colliery has been obliged to dam back the feeders, which were also in the "Tom" seam; and Victor colliery has had to do likewise. These feeders are proved to be from the marl, by the rise and fall of water at "Erin," and in a drowned-out new winning at Mengede,* and also in unfinished shafts at Hansa and Zollern collieries.

Hansa Colliery.

In this colliery, containing 2000 acres, the thickness of the chalk marl to the coal formation, which lies at 230 feet under the sea-level, is 463 feet.

The former owners of the colliery had sunk beneath a large brick tower (which, on the old German system, takes the place of pulley frames) a shaft of very large dimensions, over 24 feet in diameter, in order to make provision for very thick walls. The shaft, which was to have a finished diameter of 19 ft. 6 ins., had been sunk, as far as could be ascertained, to a depth of 267 feet, when a very large feeder of water developed itself. The pumps, which were of various dimensions, from 24 in. down to 8 and 10 in. diam., and the pumping power, which consisted of a powerful single-acting beam engine and a "Fahrkunst" or man-engine, proved, under the system adopted, insufficient to deal with the feeder, which was said to amount to between 300 and 400 cub. ft. per minute. The shaft was abandoned, and was full of water when the writers took possession, the water passing away through a conduit drift at bank. The shaft sides were framed with timber from the bottom of the sink-wall downwards, and each pump was framed or collared in, hard and fast, to these timbers, each new pump length having to be attached below; the wind-bores were telescoped to admit of sinking, but there were no suitable means for changing clacks and buckets, which were of old-fashioned construction; the pump spears were wrought-iron rods, with fished and collared

* At the shaft at Mengede preparation has been made for sinking.

joints. Thus, notwithstanding the large size of the shaft, there was very little free space left, and but little information was to be gained as to the state of the shaft.

The writers therefore considered it preferable to commence operations in the second shaft. This second shaft was free of timber and pumps, having been sunk by the original company to a depth of about 123 feet, namely through the quicksands and well into the marl, where up to that time no feeder of any importance had been met with. This shaft was also of very large size; so that, after pumping it out, a foundation was taken for a wall, which was carried up to bank, and inside of this the tubbing was fixed with a net diameter of 14 ft. 5 in. (14 ft. Rhenish). This work was commenced on 11th August, 1866. The shaft having been tubbed up, and a wall set on for the upper 10 to 15 feet, the regular sinking of the shaft was continued in English style. Very large feeders of water had to be contended with, the largest yielding about 200 cub. ft. per minute pumped in this shaft, whilst at the same time, as a further means of relief, water in considerable quantity was pumped out of the old shaft with the beam engine already referred to.

The feeders were pumped by two 18-in. sets and a 14-in. set; the former being worked by a second-hand single-cylinder horizontal winding engine, connected with a quadrant by lay spears, or flat rods, and a crank on the fly-wheel shaft. The 14-in. set was worked by a Fahrkunst or man-engine, which stood at the old German shaft and was connected with the spur-gear of the pump by a long lay-spear carried on bogies; the stroke was about 4 ft. 6 in. in both sets of pumps, and the engines had to be driven, when the buckets got slippery, at very high speeds—15 to 19 and even 20 strokes per minute. This main feeder of water was shut off at 267 feet depth; and therefore a very heavy column of water had to be lifted.

In this way, with very insufficient pumping engines, but with the benefit of having the old shaft close by sunk into the same feeder, out of which a good deal of water was raised (thus diminishing the total quantity), and with the additional benefit that the several water-bearing fissures in the marl in this new shaft were horizontal and not vertical, the writers succeeded in sinking the shaft through

the water-bearing marl to the depth of 288 feet, and in tubbing off the accumulated total of all the feeders met with in the sinking, or between 400 to 500 cub. ft. per minute. This was accomplished on 11th August, 1867, being exactly one year from the commencement.

This second shaft was sunk without any further difficulty to the coal measures, at the depth of 463 feet, by the beginning of February, 1868; and by the end of November in the same year to the depth of 810 feet—a short distance below the first working levels. Through the lower part of the marl, where a small quantity of water was found, a short lift, or length, of open-top tubbing was set on to collect the water to the set of pumps. For the remainder of the distance the shaft was walled in suitable lifts with brick and hydraulic mortar.

Coalwork was commenced in February 1869; and in the early part of that year the shaft was sunk during the night time a further depth of about 69 feet, and walled; this work to some extent stopped the coal-getting. At a later period, in 1870, the permanent forcing sets of pumps (24-in. plungers in two lifts) were built in.

The coal seams in this colliery proved excellent; but as they do not lie at a steep angle, only two could be opened in the first instance. Within a fair time however a quantity of 500 tons a day of first-class steam, gas, and household coal was brought to market. Since then the shaft has been sunk deeper, being now 1089 feet in depth, and the production of coal is 600 to 800 tons per day, raised through this single shaft, which is used alike as winding, pumping, downcast, and upcast shaft.

The principle which the writers have invariably followed, of sinking at least two shafts at all their collieries, forced on them the choice either of winning the old No. I. shaft, which stood full of water, or of sinking a new shaft to the north-west of the working shaft above described. All the circumstances of the case, combined with the necessity that the new shaft should be the "Wetter" or upcast shaft, determined them to sink a new shaft with a diameter of 14 ft. 5 in., at a distance of 170 ft., centre to centre, from the working shaft. This was to be done in a very superior manner, with the best construction of cast-iron tubbing, lined inside with fire-brick, through the water-bearing measures of the marl; and thence downward

with fire-brick walling through the remainder of the shaft, down at least to the level of the furnace drift. The work was to be carried out gradually, as suited the convenience of the company. Various circumstances, but especially the war with France, prevented any progress with this new shaft (now called No. II.) until June 1871, when the great sink wall through the quicksand overlying the upper or soft marl was commenced. From that time, with various suspensions of the work for short and long periods, the sinking and tubbing were continued up to 13th October, 1876, when the shaft had reached its present depth of 351 ft.: further progress was then finally suspended for want of funds.

Fig. 18, Plate 65, shows a working section of this new No. II. shaft from the surface to its present bottom; and Figs. 19 to 25 show details of the walling, tubbing, and foundation or wedging cribs. Referring to those drawings, the writers would call attention to the difficulties encountered in getting down the sink-wall to the depth of 50 ft.; to the improved system of laying the wedging cribs with pass-pipes and self-acting valves, Figs. 23 to 25, for escape of the compressed air and gases; to the facilities, hereafter more specially referred to, afforded by the system in dealing with feeders, when met with in horizontal fissures; and to the greater difficulties encountered when, as shown in the 7th and 8th lifts of tubbing, and in the lowest part of this shaft, a nearly vertical fissure happens to come within the area of the sinking.

The great feeder of water was, as expected, met in a horizontal fissure at the bottom of the 5th lift of tubbing; and a similar feeder at the lower part of the 6th lift. These were effectually tubbed off at the depth of 295 ft.; and judging from their previous operations in the working shaft No. I., only 170 ft. distant, the writers hoped to have now shut out all the feeders.

In this hope they were at first sustained by the results of three borings made at this level in different parts of the shaft bottom, which showed no water below. But upon continuing the sinking of the 7th lift they encountered within the area of the shaft a vertical fissure, which let in the whole of the marl waters shut out in the upper lifts, both in larger quantity, and with the increased pressure due to the greater depth.

This vertical fissure, as shown in the section, Fig. 18, Plate 65, continued within the periphery of the shaft throughout the 7th lift; and, though showing a tendency to lead out of the shaft, it still continues to the present bottom.

The upper feeders had been easily dealt with; but the accumulated supplies brought together by this vertical fissure gave, even after long pumping and when the men were working at the full depth of 351 ft., a supply of water to be pumped of over 470 cub. ft. per minute; and this notwithstanding the wedging off of a portion of the total feeder (exceeding 600 cub. ft. per minute), by means of pine-wood wedges driven into the fissure itself.

To deal with these feeders, the writers had at first a horizontal single-cylinder winding engine, 40 in. diam. and about 6 ft. stroke. This was at the south side of the shaft, and worked direct off the main crank by spears of considerable length, to which were attached two wrought-iron quadrants. To these were hung an 18-in. and 19-in. set of pumps, with a stroke of about 5 ft. At a later period another horizontal winding engine, with a single cylinder 28 in. diam., was erected to the north of the shaft, and worked an 18-in. set with about 4 ft. stroke off the back end of the piston rod. Subsequently a direct-acting vertical engine, with 36-in. cylinder and about 6-ft. stroke, working a 21-in. set of pumps, was erected over the shaft. Upon meeting with the vertical fissure however, this engine proved insufficient, and was at a later period removed; and in its stead was erected a direct-acting engine with 72-in. cylinder and 11 ft. stroke, which worked two 21-in. sets of pumps.

All these pumps were hung in with ground spears, but with wind-bores resting on the bottom; and delivered direct to the surface. After meeting with the vertical fissure, the buckets and clacks were all obliged to be changed, and that frequently, at bank; the buckets having each time to be drawn, and the clacks fished—a tedious and laborious operation from such a depth. Upon getting into the more sandy part of the marl, near the present bottom, these changes became more frequent, the leathers wearing much faster, owing to the high speed, increased height of column, and action of the sand. This is an evil for which it is most desirable to find a remedy.

Zollern Colliery.

In this colliery, situated near Kirchlinde and containing 3000 acres, two shafts were commenced by the original company, much nearer to the southern outcrop of the marl formation than in the collieries previously described. In consequence, the thickness of the marl is only 351 ft. to the surface of the coal measures, which at this point is only about 49 ft. under the level of the sea.

This position of the shafts had the disadvantage of being nearer to the supplies of water from streams on the surface; from one of which the writers subsequently discovered water flowing regularly into the marl, which is more fissured and broken near the outcrop.

Though the site, for the reason above stated, and also as regards its position in the colliery itself, was not well chosen, yet the plans of the colliery buildings, boilers, machinery, &c., were on a very large scale, and the boilers and engines powerful and good. The former company are believed to have commenced work about 1856, by sinking two large round shafts, 24 to 25 feet in diameter, intended for brick walls of great thickness, as at that time applied by German mining engineers for damming back the water. These shafts were sunk to the level of the first water feeder, which was met at about 182 feet from the surface, or about 139 ft. 6 in. below an adit which had been constructed for carrying off the water from the pumps.

The general section, Fig. 26, Plate 66, and the enlargement of the bottom, Figs. 28 and 30, Plates 67 and 68, show clearly the condition in which the writers found both shafts as sunk down to feeder No. 1; and Figs. 29 and 31 show the manner in which they finished them, down to the feeder No. 2 in shaft No. I., and to the feeder No. 1 in shaft No. II. This latter shaft, as mentioned below, they subsequently completed down to its present depth of 943 feet, for coalwork, pumping, and ventilation.

It will be seen from the plan in Fig. 26, Plate 66, that in shaft No. I. the German engineers had ten sets of pumps firmly built into the shaft, with an enormous mass of timber framing; according to the system of that time the wind-bores were movable, or telescopic, so

that they could be removed on firing shots or changing; and the pumps were lengthened by common pump pipes (each one lachter, or 6 ft. 10 in. in length) added on below in the shaft. Thus the space, even in these shafts of such great dimensions, was so encumbered with timber as to render sinking, even with moderate quantities of water, a very slow, expensive, and difficult operation. The writers have little doubt that when the feeder No. 1 was first met with, and even before it was widened out by the constant flow of water, it must have yielded 600 cub. ft. per minute. Under such circumstances, and with the inability in some of the pumps to change either buckets or clacks, for packing, at the surface, it is only wonderful that the engineers succeeded, even in course of time, by continuous pumping and partially exhausting the feeder, in sinking the sump, and in preparing, as shown at bottom in the section, Fig. 26, Plate 66, the foundation for the great walling below the first feeder.

In April 1867 the writers, having acquired the colliery, commenced preparations for recovering shaft No. I. They encountered great difficulties in the commencement; but by hanging in one large set of pumps, 32 in. diameter, they so far lowered the water as to enable them to take out the German pumps and timber, and then to hang in other large sets of 18 in., 19 in. and 20 in. diameter, as hereinafter mentioned, and as shown in Fig. 27, Plate 66; and by 30th November 1867, after wedging off part of the supply of water coming from the horizontal cleft or fissure, they were enabled to commence cutting out the foundation for the wedging cribs, designed for the tubbing of a shaft 17 ft. 6 in. diameter. They adopted this dimension as that most suitable, according to the extensive experience they had obtained in the opening out of such large coal-fields, where the coal formation with its numerous beds is likely to reach 2,500 or 3,000 feet depth below the surface.

This size of shaft compelled the writers to cast, at their "Vulcan" Iron Works on the Rhine, tubbing and wedging cribs of proportionately increased dimensions and thickness, and of improved construction with greater width of flanges. This caused some delay; but though over 600 cub. ft. of water per minute was being pumped from the first feeder in shaft No. I. (this water coming

through the crevices left by the rough wedging in the fissure), the tubbing of the upper lift above this first fissure was set, and completed up to the level of the delivering drift, by 6th March 1868, as shown in Fig. 28, Plate 67.

On further sinking shaft No. I. to the second feeder, it was found that there was such a connection between the feeders in the two shafts that it was advisable and economical, both as to time, cost, and application of steam power, to pump the water and carry on the operations in both shafts together.

Accordingly a direct-acting 72-in. cylinder engine of 11 ft. stroke was erected over shaft No. II.; a Cornish beam-engine, 84-in. cylinder and about 10 ft. stroke, at shaft No. I.; and lastly, a horizontal winding-engine of 42-in. cylinder and 6 ft. stroke, between the two shafts, working with lay spears and quadrants into both shafts. By this means the writers were enabled to work together nine sets of pumps, as follows:—

2 sets of 32 inches diameter.
2 „ „ 21 „ „
2 „ „ 19 „ „
2 „ „ 18 „ „
1 „ „ 16 „ „

With these they pumped out of the two shafts 1,200 cub. ft. per minute of the water which escaped through the wedging of the natural fissures in the marl; and completed the closure of the tubbing for the first feeder in shaft No. II. on 9th August 1868, as shown in Fig. 31, Plate 68; and for the second feeder in shaft No. I. on 15th November 1868, as shown in Fig. 29, Plate 67.

In the winter of 1868 further operations were suspended, owing to the want of a railway, which had been long previously agreed upon by the Cologne and Minden Railway Company, but not constructed. This suspension continued for the same causes until 1870, when, to ascertain what further feeders were to be expected in sinking shaft No. II., the writers had a boring carefully made a little to the west thereof. This boring gave very precisely the positions and probable dimensions of the water-bearing fissures, which they might

expect to meet in sinking the shaft to the coal measures; and these indications, upon the subsequent sinking, proved to be correct.

The railway company still failing to construct the branch railway, the writers were at last forced to construct, at their company's expense, a horse tramway along the public road from Zollern to Hansa colliery; and sinking operations were re-commenced in shaft No. II. in August 1871. Four more feeders, Nos. 2 to 5, were sunk through and tubbed off successfully to the depth of 292 feet, before the end of March 1872; and all water was so completely shut out that the remainder of the shaft-sinking and walling to the net diameter of 17 ft. 6 in. was carried out, first to the coal measures at the depth of 357 feet, and then to the present bottom at 943 feet, without any pumps whatsoever in the shaft.

The quantities of water shut out by the several lifts of tubbing were carefully measured as follows:—*

Down to, and inclusive of, the first four feeders . .	1160	cub. ft.	per min.
The fifth feeder	150	"	"
The sixth or lowest feeder	100	"	"
Total .	1410	"	"

This total is a quantity of water rarely met with in shaft-sinking; but it was shut out so effectually in this large shaft as to enable it to be completed to the bottom without pumps.

The connection to a railway was not made until 1879, up to which time only preparatory work could be carried on in opening out the colliery from the shaft; but since then the pit has been continually worked, producing now about 750 tons of coal per day, and with very little water to pump. It is worked entirely through the single shaft No. II.; but at an early period a second shaft must be completed.

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* In all cases the quantites of water were actually measured at an overflow weir, in a watercourse constructed for the purpose.

General remarks and deductions.

The foregoing description of the geological features of the district, and short history of the writers' shaft-sinking operations therein, afford suggestive facts for the consideration of mechanical and mining engineers, especially as regards the pumping of water, and the effectually securing its ultimate exclusion from the shaft. Upon the mechanical arrangements, connected with the use of the shafts for winding and ventilation, the writers do not propose to touch, further than to record their conviction of the absolute necessity of having at least two shafts, and the great importance of these shafts being of large diameter, and having smooth sides made permanently secure either by means of cast-iron tubbing or of solid walling. The shafts should be to the utmost possible extent free from obstructions, especially timber structures or framing, which in case of accident from fire, falling cages, or explosions, often stop the ingress and egress, and so bury men and horses alive.

In the Westphalian coal district, and especially where the coal is covered by the chalk or marl formation, no expense or care should be spared in designing and constructing the shafts, now that its enormous richness is proved, containing as it does from sixty to eighty workable seams of all the best classes of coal. The depth of the coal formation is 3000 to 4000 feet, ensuring a long duration of production; and the right of property therein is in fact a fee simple, independent of all rights in the surface of the land, and subject only to a small duty to the State of 2 per cent. upon the selling value of the coal sent to market.

In this matter, as in most others in Germany, it is the owners who execute works, and develop the resources of a property; therefore, when the capital or expenditure in a colliery, including say 2,500 acres of these coal-fields, is said to amount to some £280,000, it is to be understood as including possession for ever of all the underground minerals; of all lands, rights of way, &c., purchased on the surface; also of all the works, machinery, and houses erected; and finally of the legal right to erect such others as may be required for the further development of the mine, including the right to

expropriate, on reasonable terms, the surface land required for such further development.

Returning to engineering matters, it is to be observed that all the marl (except a few fathoms of the soft upper marl near the surface), and the two greensand strata, with the intermediate layer of gault (which here is generally a very compact strong white marl), are in the form of solid rock. This, in shaft-sinking with manual labour, must for the most part be blasted with gunpowder or dynamite. The latter has been found by the writers to be the quickest and most effective explosive in blasting under water, requiring no tamping—a very important point in sinking through the marl feeders, where four-fifths of the shots must be under water.

In their sinking operations the writers were generally pioneers, sinking shafts in advance in the virgin strata of the district; and therefore were rarely able, notwithstanding all precautions, to estimate or foresee exactly with what quantities of water they would have to deal, and consequently what amount of steam power and pumps should be provided in the first instance. Although their trial borings, as previously stated, luckily helped them in several cases, and proved correct, yet in others, where vertical fissures occurred, they were deceived.

But from the earliest period the writers saw the advantage of sinking at the same time two shafts of large dimensions and contiguous to each other—an advantage especially illustrated at the Erin, Hansa, and Zollern collieries. Not only is this best for the sinking operations, but in the end it is most suitable from an economical point of view, in regard to surface arrangements and connection with railways.

With two shafts—in which the feeders are either naturally connected, or can be artificially connected by small drifts when necessary, even though the extent of surfaee discharging water be somewhat increased thereby—the advantages in the disposal and application of the pumping power for combating heavy feeders are so obvious as scarcely to require explanation.

After all, the whole question in Westphalia, and also in many other countries where the material to be sunk through is solid

rock or other sound and strong formation, is simply one of pumping, from certain depths in vertical shafts, certain quantities of water per minute. It is not complicated with the risk of finding running sand mixed with the water at great depths, as under the magnesian limestone in parts of the North of England; or of meeting with clays which will swell and slip upon being brought in contact with water, as in other districts. In fact, the greater part of the difficulties encountered by the writers and others in this district arose from the three following causes:—

1. In the first instance, a want of thorough knowledge of the marl formation and its water feeders.

2. A consequent insufficient provision of pumping power, of suitable pumps, and of suitable modes of using them; and especially the neglect of the advantages of two contiguous shafts.

3. The shrinking of capitalists from the providing of adequate capital in the first instance—a false economy which has often caused the total loss of capital already spent, and many years' delay in developing the riches of the collieries.

In sinking shafts through heavy feeders of water, as for instance the Zollern shafts, Nos. I. and II., the sinkers must invariably work in water, both while drilling the holes for blasting in the sump, under the thick cast-iron wind-bores of the pumps, and subsequently while breaking up and removing the materials blasted. Now, whilst it is necessary to maintain the sump at such a depth that the wind-bores can get their full supply of water, without drawing air, yet on the other hand men cannot work efficiently if the water be more than knee-deep, or say 2 feet. Consequently the pumps must be worked by a short quick stroke; and the strokes of the several pumps must, as far as possible, be so timed as to keep the water regularly and steadily down to the proper level in the shaft. Yet this, with large feeders, is often most difficult to do, and the missing of a stroke or two often causes the men to be up to their waists in water: especially when only one shaft is being sunk, or when the two shafts are small. Again, in cases of buckets or clacks suddenly failing, the men have at times to scramble for their lives up the pumps, or else up wire-rope ladders, which the writers

always provided when dealing with heavy feeders, to afford a means of escape.

The combat in such cases, if it is to attain a successful result, requires the utmost perseverance and courage on the part of all concerned; the men must be relieved every four or six hours, and, in addition to receiving adequate wages, should be encouraged during each shift by a premium on every inch they lower the sets of pumps; the work must of course be continued day and night, and in extreme cases on Sundays and holidays also, without intermission. The natural feeders, when met with, must be wedged off, both to assist in reducing the quantity of water, and to prevent it from dashing out, with all the force due to the pressure of its source, over the bodies and heads of the sinkers. Under all these difficulties, whenever a solid homogeneous layer of marl, free from fissures, is found below the feeder, a perfectly smooth, level, and carefully made bed must be cut out and chiselled off, as a foundation for the wedging cribs upon which a length of tubbing is subsequently built.

Notwithstanding these difficulties, and many other sources of care and anxiety in all the details of the work, the writers maintain that, whenever the water can be pumped during the sinking of the shafts, the system of shutting off the water from the shafts by tubbing, both for the present and for all future time, is the best that can be adopted; and this for the following reasons.

1. Every portion of the work is seen and inspected, and can be properly treated and proved as it progresses from the surface downwards.

2. The nature of the strata, and the separate quantities of the feeders &c., are not only seen, but, upon closing each lift of tubbing, the feeders, so far as regards the space occupied by the shaft, are restored to their natural channels; while by the wedging cribs they are at the same time shut off from communicating with each other. This is an important matter, because, in case of accident, the repairs of any one lift of tubbing, or the removal of a broken segment, can be effected without interfering with the water in other lifts of tubbing.

3. The cast-iron tubbing constructed in segments, as shown in Figs. 19 to 22, Plate 65, allows of sinking large shafts as easily as

small ones: the writers having constructed shafts from 10 ft. to 17 ft. 6 in. diameter.

4. Such segments can be constructed either with brackets, or with large openings, or with taps of suitable strength and dimensions; thus giving the means of attaching pumps, or building in buntons for standing sets, or pipes for the supply of water, either to bank for surface purposes, or down the pit for hydraulic power &c.

In short, by this system, one is master of the work as it proceeds, and it can therefore be carried out more quickly than by any other system known to the writers, and in the great majority of cases at less expense on the whole.

The old German plan of attempting to shut out the water with brick walls is of course exploded; and the only system with which to compare the tubbing system in its present improved state is that known as the "Kind-Chaudron." This system * is very ingenious, and has many merits, especially for boring out small trial shafts, where water is known to exist in the overlying measures; or in unexplored countries for viewing or examining the underlying minerals. It has often occurred to the writers that it might be used for sinking auxiliary upcast shafts, for the constant discharge of gases from the goaf or broken, lying to the rise of the colliery; instead of allowing these gases to accumulate below, and upon a fall of roof, depression of barometer, or other accidental cause, to flow back into the working parts of the mine and produce explosions.

The Kind-Chaudron system is also unquestionably to be recommended, when the supply of water in the upper measures, above the coal or other minerals, is practically speaking unlimited; as for instance in open strata, communicating directly with the sea, inland lakes, or large rivers—in other words (repeating the writers' previous remark) where the water cannot be pumped. This, of course, virtually includes all cases where, even under the best system and with suitable means, it would not pay to pump the water and exclude it with tubbing.

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* See description in Mr. Simon's paper, Journal of Iron and Steel Institute, 1877, p. 187.

The writers' experience of the Kind-Chaudron system as applied at Dahlbusch in Westphalia (on which a report has been published by Herr Direktor Schulz) was not favourable, either as tried twenty-seven years ago, or at a later period; because the quantity of water was not great, as was proved at the Hibernia Colliery, which lies to the dip of Dahlbusch, and very near it. Here therefore, in their opinion, the system was not necessary, whilst the time occupied in sinking was much greater than with the tubbing system.

Again, looking to the Shamrock and Erin collieries, where the water-bearing strata were all near the surface, it will be seen that in carrying out the Kind-Chaudron system in such cases, and so keeping the water in the shaft the whole time that the boring is proceeding, one would be liable to be deceived into carrying the boring and the cast-iron "cuvelage" or casing down the whole depth to the coal measures; though in fact, as shown above, the marl was completely free from water below the respective levels of 126 ft. and 176 ft. 6 in., so that the writers were enabled to sink and wall the shaft without pumps, and this at the rate of about 90 feet per month in Erin colliery, where the shafts were finished to the net diameter of 14 ft. 5 in.

Speaking generally, the objections which the writers have to the Kind-Chaudron system, at least as applied to their district, are as follows.

1. The work is, so to say, carried out in the dark, with the shaft full of water.

2. All the feeders of water are brought into connection with each other, both surface feeders and under feeders.

3. The shafts are by the very nature of the machinery limited to a very small diameter, too small for the great depth of the coal measures; and this limitation of diameter restricts the engineer to the use of a very thin bed of beton or cement, at the back of the cast-iron "cuvelage."

4. The whole "cuvelage" being necessarily joined into one length, from the surface to the foundation (which itself is formed by a boring machine in the dark, *i.e.* under water), the pressure of the accumulated feeders is brought to bear over the whole height of the

tube; and in case of any accident to any part of this cast-iron envelope, it would be liable to vent into the shaft the whole of the accumulated feeders.

5. Another objection, in the Westphalian district, is the risk to which the coal measures, otherwise dry, are exposed of having the feeders in the marl let down to much lower levels, by boring through the Bohn-erz, or layer of iron-ore, which shuts them off. Indeed the writers are convinced that this has been done in many cases with the ordinary trial bore-holes, where they have not afterwards been efficiently stopped.

There are perhaps cases where, for special purposes or for works of temporary duration in shallow depths, this system may with advantage be applied even in parts of the Westphalian district; but the number of such cases is probably small.

If the above objections to this system be justified, the English system of tubbing must still be adhered to; and then, for its full and economical application to this district, the great desideratum, and the great problem to be solved by practical engineers, is to improve, and, if possible, to simplify the method of pumping.

The pumping system which the writers substituted for that which previously existed in Westphalia, comprises the hanging in of pumps with ground-spears and wire ropes; the use of large pumps with long wrought-iron barrels, instead of common (or delivery) pumps of cast-iron; the provision of wind-bores of such a strength that the marl or other rock could be shot away from under them without injury; and the use of large wooden spears for the pump-rods, instead of the common wrought-iron spears. This constituted altogether an improvement, and was effectual, as shown above, for the pumping from considerable depths of feeders yielding from 400 to 1,200 cub. ft. of water per minute. But the writers freely confess to a feeling that for shaft-sinking through heavy feeders of water—and especially where these occur at greater depth than they had to deal with in the above cases—still further improvements and simplifications are urgently required.

With regard to the unwatering of drowned-out mines, such as Erin colliery now is, the writers, after many conferences with Mr. Henry

Davey, and due consideration of his proposals, see their way clearly enough, especially when two complete contiguous shafts are in existence; and entertain no doubt of the success of the proposed operations, if carried out by men of suitable experience in such works. But it is with reference to shaft-sinking as above mentioned, with feeders at greater depths, and where the pumps with their great number and weight, together with the strong heavy timber framing which is required to keep them in their places, and through which they have to slide, occupy so large a portion of the shaft, and take so much time both in fixing and in removing, that the writers wish to raise a question, which may be stated as follows :—

Whether the problem of procuring the delivery of the water from the bottom to the top of the shaft cannot be so solved, by some radical change or improvement in the pumping arrangements, as to allow of the sinkers working far more effectually than at present?

Is it possible by a change in the construction of pumps, or by the application of steam, hydraulic, or electric power, to attain a continuous discharge of the water; say, for example, of 400 to 600 cubic feet of water per minute, from the bottom of a shaft 600 to 800 feet deep, and having a diameter of 16 feet: the discharge to be as rapid as the inflow of the feeders into the shaft, so as to avoid unduly raising the level of the water on the men working at the bottom?

The writers have shown that shafts of 14 ft. 5 in. diameter can be excavated in dry marl, and securely walled and finished, at a rate exceeding 80 feet per month, exclusive of Sundays. Shafts of the same dimensions, secured with cast-iron tubbing, where little or no water is present, can be, and have been, completed at about the same rate. But in shafts with moderate feeders of water the progress is very much slower; and with large feeders at considerable depths the progress becomes a question of inches, especially when, as often happened in the writers' experience, the feeders were so strong as not to allow of changing the buckets at their doors. In that case the buckets, with their long length of wet spears, had to be drawn to the surface, the spears being disconnected in lengths, and again securely bolted together on lowering into their places; during all which time of course the sinkers were out of the bottom and the sinking was suspended.

To compare the relative cost of shaft-sinking under the various systems and the various circumstances referred to—large or small shafts, sunk dry or with feeders of various quantities—would in general be of little practical use. Each case is very largely dependent upon its own particular circumstances—the existence or non-existence of adequate engine power from the outset, knowledge of the strata, and adequate supplies of capital to prevent the wasteful expenditure caused by delay. To state any general average expenditure per foot or fathom of shaft sunk, under these various circumstances, would be illusory, and more calculated to injure than to benefit the progress of mining engineering.

The writers cannot conclude without referring for a moment to the project now so much canvassed by the public in England, namely the tunnel under the British Channel. This tunnel is proposed to be driven through the chalk formation, which immediately overlies the greensand and gault. Without a thorough investigation of these strata, and a comparison with those in the same geological positions in Westphalia, they would not of course presume to express a definite opinion; but they invite attention to the foregoing description of their twenty-seven years' practical experience of this formation, and to the positive facts they have stated, showing how deceptive even the most careful examination and actual borings—extending over a district exceeding 40 miles in length — have often proved. From their experience they must state their conviction that neither geologists nor engineers are justified in assuming that water will not be met with in driving the tunnel; or in assuming that clefts and fissures once met with, and once let into the open space caused by the tunnel, may not rapidly open out into wide channels, extending through the comparatively slight thickness left between the tunnel and the bottom of the sea.

Abstract of Discussion on Mining Machinery.

Mr. DAVEY said he must apologise for the sketchy and discursive nature of his paper. The reason partly was that he had depended upon getting information from several sources, in which he had been disappointed. In particular Mr. W. T. Mulvany, a gentleman largely connected with the coal and iron district in Westphalia, who had had almost the widest experience of any man he knew in putting down shafts in very heavily watered strata, had kindly promised to furnish him with notes of his experience. He had not received these notes in time to embody them in his paper, but they would be printed as an appendix. Mr. Mulvany had kindly sent with them some diagrams, Figs. 17 to 31, Plates 64 to 68; and he would draw especial attention to Fig. 18, Plate 65, which showed the methods employed in putting down a particular shaft at Hansa Colliery, and would interest all who were concerned with large pumping operations. The total quantity of water ultimately tubbed back in another shaft, at Zollern Colliery, was 8,800 gallons per minute. Fig. 30, Plate 68, showed some of the pumps in position at the bottom of that shaft, and the minimum depth of water that the sinkers had to work in; sometimes it was almost up to their shoulders. Hence the very great difficulty of sinking in such heavily-watered strata. In that and the fellow shaft, each of 17 ft. 6 in. diameter, there were finally the following pumps, altogether as many as nine in number:—two of 32 in. diam.; two of 21 in.; two of 19 in.; two of 18 in.; one of 16 in. The enormous expense could be inferred of sinking shafts filled by so many pumps, and by all the appliances for lifting the pumps in case of flooding—which had actually occurred several times in the course of the operations. When, for instance, there was a breakage in the lower part of any pump, the whole pump, weighing in some cases 60 or 70 tons, had to be lifted bodily to the surface. Looking at these facts, he thought there was a sufficient excuse for his suggesting in the paper, however crudely, that other methods should be sought after.

In proposing to put down a special pumping shaft to the bottom

of the water-bearing strata, he should explain that it very often happened the water-bearing strata did not extend more than one-third or one-half the depth of the pit. It was easily seen that the Kind-Chaudron system of sinking was not an economical one as compared with blasting, for the simple reason that in that system the whole of the rock sunk through had to be reduced to powder; and an enormous amount of mechanical power must clearly be expended to go through 600 ft. or 700 ft. of solid rock with a pit of 16 or 17 ft. diameter, pounding the rock to mud in the operation. In blasting, on the other hand, the rock was got out in large lumps, and with much greater economy; but the expense of pumping, where a large quantity of water had to be dealt with, was enormous, and the delay was very great. As described in the appendix, page 360, in the Rhine province of Westphalia the water-bearing stratum, which was chalk or marl, often extended to less than half the depth of the shaft; so that, even if recourse had been had to an expensive system of sinking the pumping shaft, it would only have been necessary to sink half the depth by that means. As only a small shaft was necessary for pumping, a shaft sufficiently large to take the pumps might be sunk to the bottom of the water-bearing strata, leaving the fissures all open, slinging the pumps, and lowering them gradually down. Then a larger shaft could afterwards be put down alongside, in dry ground, without interruption from flooding. It was true there were cases where a well was put down within a few yards of another well, and where, although the first well was kept dry, the second still required pumping; but those were exceptional. Generally speaking, the water-bearing strata overlying the coal formations were so open that pumping from one spot laid dry all the adjoining ground within a certain cone, of which the apex was the snore-pipe of the pump.

Mr. David Greig asked for further information with respect to the Kind-Chaudron process, as applied at Whitburn near Tynemouth, and elsewhere. On the question of haulage and general working underground, he thought the paper might have gone further into

detail than it had done. The working of engines underground with pressure water was, he thought, inadmissible, unless the water should pass away by gravitation after being used. As far as his experience went, the only direction for improvement lay in the employment of compressed air. The paper spoke of the percentage of efficiency with air being only 33 as compared with 50 per cent. for water. Even supposing that to be right—which he did not admit, for he thought the efficiency for air was understated—the extra cost of working with air would be more than counterbalanced by its convenience. Further, it was of the utmost importance, in view of the many contingencies in mining, that power should be sent all over a mine ; and air was a very convenient means of having power in every quarter. The drilling of the holes for the shots might also be done with it. In many ironstone mines air was laid all through them, and the shot-holes were drilled by compressed-air machinery, which saved 2*d.* per ton. That was impracticable with water. What was now wanted was to provide some hauling power at every part of a mine, so that there should be no need of tail-ropes, and the tubs could be taken in any direction. This could be effected by laying air-pipes throughout the mine, and taking the air to work locomotives underground.

The paper had given, p. 327–8, a description of a winding engine which was doing a large amount of duty; but an engine recently put up by Messrs. Brown and Adams at Harris' Navigation Colliery, Glamorganshire, was capable of lifting 5 tons of coal every $1\frac{1}{2}$ minute from a depth of 700 yards.* There the difficulty of increasing the output arose, not from the engine, but from the fact that the coal could not be brought out quick enough to the bottom of the winding shaft. The question was a very difficult one, and he did not agree with having such large engines put down to bring up so large a quantity at a time. It was much better, where practicable, to have several smaller engines and to bring up less coal each time, with less difficulty of handling at the bottom of the shaft.

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* See Minutes of Proceedings Inst. C.E., vol. lxiv., pp. 47–48. Messrs. Brown and Adams have since kindly informed the Secretary that this engine is not yet doing its full duty, but that they hope to average 1500 tons of coal in ten hours.

Mr. E. A. Cowper understood that the trip arrangement, shown in Fig. 12, Plate 63, was not intended to move the valve itself, but just to let it go. That seemed to be a safe arrangement, and he was glad to see it applied, so that if a valve broke, or something went wrong, there would not be a complete break-down of the engine owing to its getting too much steam and running away. There was always more or less distance to stop in; and by means of an elastic resistance or cushion the engine could be brought up with much less shock. The pumping arrangement in Fig. 8, Plate 61, with two bell-cranks facing each other and connected, was, he thought, a very good one; for while one bell-crank was working upwards the other was working downwards, and their weights balanced each other, while the advantage of the inertia and momentum of both was also obtained, thus enabling more expansion to be used than when one weight only came into play. Besides this, there was nothing hanging over the pit except the ends of the two bell-cranks.

Mr. Benjamin Walker, referring to the application of separate condensing engines, which was included in page 327 among the chief modern improvements in direct-acting winding engines, mentioned that many years ago his firm had sent to Westphalia some large blast-furnace blowing engines, which were worked with separate condensers with very great advantage. They could find out exactly the speed at which the condenser should be worked, and give the minimum amount of power required to drive it, and they could also make the small engine driving it work at a greater speed than they could the large engines. The small engine was also very much more under command. They had applied the system also to a large number of rail-rolling engines. They generally adopted a surface condenser, as it avoided the chance of water getting from the condenser into the cylinder, when the main engines were suddenly stopped.

With regard to the efficiency of compressed air, he wished to follow up what Mr. Greig had stated, by saying that it was not his experience that so great a loss as 70 per cent. took place. The 50 to 60 per cent. efficiency given in the paper for water-pressure, page 331,

was doubtless true with regard to a very well constructed hydraulic engine; but he was sure there were many hydraulic engines which did not give out anything like 50 or 60 per cent. of the power put into them; and he was sure there were many well constructed air engines that gave out a great deal more than 25 or 33 per cent. The pressure of 45 lbs. per sq. in. was in his opinion the best pressure for air, giving the least waste. With higher pressures the waste increased very rapidly. Some years ago he had spent a great deal of time and money in trying to work coal-getting machinery by compressed air. The air mains were laid underground to a distance of three or four miles from the mouth of the pit. The difficulty with the pipe-joints was very considerable; but when the miner had set the machine to work, the advantage of having fresh air close to his mouth was a very great one. He could conceive no system of working a coal-getting machine, or a small pump, or a hauling engine, at three miles from the mouth of the pit, that would be really so economical as compressed air.

Four years ago he had to make for the Midland Railway a large overhead travelling crane; and one of the conditions was that it should start with its load as slowly as desired, and then be able to go at a high speed. To accomplish that object compressed air was used. In the centre of the shop was put a large drum 6 ft. diam., round which was wound an india-rubber and canvas hose-pipe, coupled to a pair of cylinders working a crank on the crane. A pair of small air-compressors was used, having steam cylinders only $5\frac{1}{2}$ in. diam., and air-cylinders only 6 in. diam., delivering into an air vessel. The compressors would run as fast or as slow as could be wished. The exhaust from the crane was fresh air, which helped to ventilate the works. If there had been anything like the loss spoken of in the paper, the air-compressors, which had to go comparatively slowly, would have had to be much larger compared with the cylinders on the crane. The flexible pipe for carrying the compressed air, which had been expected to give some trouble, had been four years at work and had never cost sixpence for repair; it was as good today as when it was put on. There was just a counterweight on the drum to keep the pipe taut; and as the crane

travelled the pipe was pulled outwards, and came back again of itself under the action of the counterweight. The great advantage of working a crane in that manner was that it could be started as slowly as was liked, and then as the men felt their way with the load they could run the crane up to a high speed. To travel in a shop 200 ft. long by any other means that he knew of would take twice the time. With this plan everything was clear out of the way; there were no connections, the friction &c. was slight, and the crane worked as easily as if it were nothing more than a rope.

In quoting the failure of the fly-wheels of pumping engines at a mine in Nevada, page 329, he thought the paper had given an old friend an unnecessary kick. The fly-wheel, when applied to making an engine work economically, was a most valuable appliance; where the spokes had been broken out at a low speed of only a few revolutions per minute, their failure he considered was simply due to bad construction, and was not the fault of the system.

Mr. Henry Lawrence thought that if it were attempted to put pumps into a bore-hole, as shown in Fig. 7, Plate 61, it might be found that a stoppage would occur similar to what took place in carrying out the Kind-Chaudron process at Whitburn Colliery. It had there been proposed to sink a 15-ft. pit; a 4-ft. hole had first been bored in the centre of the large pit, and carried down he believed 50 or 60 feet; but when the large borer was afterwards put in, to increase the shaft to its full size, so much of the débris fell into the bottom of the 4-ft. hole that it all stuck fast, and when the circular pump was put down to pump up the débris, the stuff was positively set hard. Therefore, after the 4-ft. hole had been sunk again through the next length, a long cylindrical bucket of wrought iron was made, and just suspended in the top of the 4-ft. hole, so that when the large borers were working the rock off the outside of the pit, it simply fell into the cylindrical bucket; which after a certain time was pulled up and emptied. Working in the way proposed in the paper, he thought the pumps would soon get stopped up and would have to be drawn out. He did not agree with the author that sinking in that way would be done better than by the

Chaudron process. At Whitburn a very handsome fortune had been spent in trying to sink the pit in the usual way, as in Westphalia; and that having failed, the only way in which the pits could be got down was by the Chaudron process.

He did not agree with Mr. Greig in advocating small winding engines in very deep shafts; because in deep shafts the more the engines could bring up at one time the better. There was also less work upon the rope than with smaller engines winding a greater number of times. For instance, at Silksworth Colliery near Sunderland there were a pair of 40-inch winding engines, working a conical drum weighing 50 tons, and these engines raised from 612 yards depth a load of between 4 and 5 tons of coal, eight tubs at each winding; and that was done in 50 seconds. If only half that quantity were wound with a small engine, it was easy to see the loss and delay that would arise; it would be impossible ever to get the same quantity of coal out of the pit as at present.

Mr. ARNOLD LUPTON said that, to give some slight notion as to the magnitude of this subject, he might point out that in the last year there were raised in Great Britain alone upwards of 180 million tons of minerals—coal, ironstone, clay, &c.—or say 180 million cubic yards: which would make an embankment 60 feet high, 15 feet wide, and upwards of a thousand miles in length—a wall that would stretch from the Land's End to the South Foreland, and from the South Foreland to John o' Groats. At p. 319 of the paper it was mentioned that the sinking of metal mines and coal mines was much the same. But the shaft of a coal mine passed through strata, which if not horizontal were inclined at an angle measured from the horizontal, and it was sunk to a known stratum below; whereas a metal mine was gradually deepened year after year, following the lode, until, perhaps after centuries, it reached its present depth, and its maximum depth was not yet known. Therefore in coal mines a good straight round shaft was used; and in metal mines a crooked rectangular shaft, varying sometimes both in the angle of dip and in the direction in which it was sunk.

With regard to the very large question of boring, he was

rather surprised that mention had been omitted of the spring pole, which was the general method adopted in this country for shallow borings. As to the cost of boring he might give a formula, derived from some experience of his own and from the wider experience of others, which might serve as a rough guide to the approximate cost of a boring. Taking eight shillings a yard as the cost of boring for the first ten yards, then at every additional ten yards three shillings per yard should be added to the price; so that the second ten yards would be eleven shillings per yard, the third fourteen shillings per yard, and so on. In this way the average cost could be roughly ascertained. That did not include the cost of plant on the surface, such as the spring pole, winches, &c.; it was the price paid to the contractor, who brought his own rods and sharpened his own tools, but did not find the surface plant. Working out a depth of 100 yards, the cost for boring would be about £107; for 300 yards the cost would be about £772, and for 1000 yards about £7085. The bore-holes made in Germany down to a greater depth than 1000 yards showed the accuracy of that calculation. But he certainly would not profess to give any rule by which the cost of a bore-hole could really be ascertained before it was down. So many accidents arose in boring, especially in boring by rods, that it was impossible to say what the cost would be. It depended not only on the strata through which the boring was done, and on the luck that might be met with, but upon the purposes for which the bore-hole was intended. If the boring were intended to search for iron ore in the mountain limestone, the problem was very simple,—the boring would have to be continued until the ore was found, or until all the money was spent. If however the boring were through coal measures, it was needful to make an accurate section of the measures passed through, on which account the process was much slower and consequently more expensive. The old system of boring with rods was a good one for that kind of exploratory boring, because by feeling with the hand the vibration of the rods, and by the sound, the master-borer could tell when the chisel was passing from one stratum into another, and, with the additional evidence of the contents of the sludger,

what was the nature of the ground. Boring by ropes by Messrs. Mather and Platt's method was well known, and it was an excellent method, as he could testify from experience, although it was now partly eclipsed, but not permanently superseded, by the diamond rock-boring system. But in order really to study the whole question of boring, it would be necessary to go to America, where the old Chinese system of boring with a round rope had been largely adopted. For the purpose of their oil wells the Americans had put down such a vast number of holes, that they had acquired more experience within the last twenty years than the whole history of Europe could give.

As to the Kind-Chaudron system of sinking, his own lamented master, the late Mr. Parkin Jeffcock, went to France in 1864 or 1865, and brought back with him a long account of that method of boring, even then an established system there, which he had examined and found to be successful. Shortly afterwards, about 1867, Mr. Simon came to England and published a pamphlet on the subject, giving all necessary information. In 1871 Mr. Warrington Smyth read a valuable paper on the subject, which was published in the Transactions of the North of England Mining Institute, and a paper was also read by Mr. Simon before the Iron and Steel Institute in 1877; so that there had already been full information on the matter. The cost was no doubt considerable. In one instance a shaft had been sunk 96 yards deep and 12 ft. diam., at a cost of £200 a yard; in some cases more than that average amount had been spent and no successful result achieved. One reason why the system had been so much adopted in France was that the French were willing to spend vastly more money than anybody would spend in England for the purpose of developing a coal mine; Mr. Warrington Smyth had stated that in France no less than £840,000 had been spent in trying to sink to the coal measures in one district, and the attempts had failed. The average cost of establishing coal mines in France was perhaps four times as great as in England.

With regard to the system of sinking bore-holes in advance of the shaft, he did not think it was likely to be practically successful. The first few shots would jam the pump tight. As to boring by

machinery a hole 200 feet in depth (page 325), and then, after sinking the shaft to that level, continuing the bore-hole to a greater depth, why not start the big shaft at once? It had to be made, and the sooner it was begun the better, as a big shaft was wanted for pumping in during the sinking. As to the advantage afterwards to be got from a separate small pumping shaft sunk previously, as suggested in the paper, he thought that was a great mistake; it was not a little shaft that was wanted for pumping or for the upcast, but as large a shaft for the upcast as for the downcast, or nearly so. In some cases as much as nine million cubic feet or 320 tons of air per hour had to be drawn up the upcast shaft; therefore no small shaft would answer for such a purpose.

As to the percentage of useful effect from compressed air, he had made some experiments himself, which were conclusive as far as the particular engines were concerned, though not for better engines and better contrivances; and he thought the author was not far wrong as to the practical results that had hitherto been obtained. From 25 to 33 per cent. was a very common result to get as the useful effect from a compressed-air machine. But was so high an efficiency as 50 or 60 per cent. really got from hydraulic engines? That was a point upon which he hoped more information would be given. With regard to driving a pump underground by a steam engine on the surface, using a fluid rod or hydraulic transmission of power, there the pumping engine worked against a regular load; and therefore it was only necessary to design machines of the proper proportions, and the maximum effect would be obtained from the steam engine. But as to hauling engines, although there were certainly some kinds of hauling machinery where the work was tolerably regular, such as some kinds of endless-chain gear, where the engine went at the same speed all day, yet most hauling machinery had varying work, varying every minute and hour. If with a fixed load the maximum efficiency was 60 per cent., what would the efficiency be with a varying load? Would it be 20, or 10 per cent.? These were practical questions that had to be considered when putting down machinery. With reference to transmitting power underground from the surface, he believed it would be

admitted that the most economical method of transmitting power was by wire ropes, and the next by steam pipes properly covered; but compressed air was the most convenient. Water however would no doubt be extensively used; he had seen it used in a pit in South Yorkshire for hauling up an incline at a great depth below the surface, worked with pressure from the shaft as suggested in the paper. He doubted whether electricity would ever be admitted in fiery mines for machinery underground. A spark coming from a breakage in the wire, which might happen suddenly at any time, would produce a light; and that might take place just where there was an outburst of gas caused by the same fall of stone that broke the wire.

With regard to winding, the "short rope" or Koepe system of winding with a single large driving pulley instead of a drum, page 327, was all very well so long as there were simply two cages balanced one against the other over the pulley; the cages then kept the rope tight upon the pulley, and there was sufficient adhesion for winding. But suppose it were wished to repair the shaft—or suppose an accident to one cage or to the conductors, so that only one cage could be used,—how would the single pulley answer then, when there was no balance on the other side to keep the rope tight?

He did not see on what ground the suggestion was made on page 324 that caloric engines would supersede the steam engine. In his own brief experience he could remember talk about caloric engines twenty-five years ago; but the system was no nearer practical success now than it was a generation earlier.

Mr. Jeremiah Head wished to call attention to one point which had not been touched upon in the discussion; namely the ventilation of coal mines. In the present paper, and also in that of Mr. Meysey-Thompson on the previous day, the fact had been mentioned that the old furnace system of ventilating coal mines had now been almost entirely superseded by mechanical ventilators; and the inference might be that this part of mining engineering was now pretty satisfactorily settled. But during the past twelve months there had been at least twelve most disastrous colliery explosions in the

North of England, attended with terrible loss of life; and he was sure all would agree with him when he said that there was no time when a mechanical engineer felt so deeply humiliated as when he found himself unable to account for one of those disasters, or suggest how to stop them for the future. The point he wished to raise was this. All the mechanical ventilators in existence were acting, he believed, on the principle of the *exhaustion* of the air from the mines. Now it was known that, when the barometer fell, explosions might be expected; and this showed the extreme importance of keeping up a good pressure of air on the face of the coal. But as it was, if a colliery owner found he must look out for explosions because of a low barometer, all he could do with the existing ventilator was to set it going quicker: the effect of which was then still further to lower the pressure in the mine, and of course to cause any gas that was coming from the coal to exude more quickly. Therefore, without pretending to any special knowledge of the subject, it had always struck him that the right principle of mechanical ventilation in coal mines was rather to force the air through the mine by pressure than to suck it out by exhaustion. Mr. Greig and Mr. Walker had spoken as to the great value of working machines underground by means of compressed air rather than by water; and one argument they had used was the great advantage to the miner of bringing fresh air to the most remote part of the mines for ventilating purposes. Now when air was demanded in the most remote part of the mines, for working the appliances and machinery, and also for the workmen to breathe there, and above all things for keeping a pressure on the face of the coal and for diluting the noxious gases, it seemed worth enquiring whether some means could not be adopted for changing the present system of ventilation by exhaustion to one of forcing air for all these purposes to the extreme ends of the mine, and then letting it flow back as it could.

Mr. W. S. Hall thought the variable expansion gear shown in Fig. 15, Plate 62, was the most promising arrangement of the sort he had seen brought forward. As the author had well said, most of the previous attempts had failed through complication; but the proposed

plan appeared to provide a solution of the difficulty. With regard to winding machinery, the paper gave two methods of counterbalancing—one by a conical drum, and the other by tail ropes suspended under the cages. Each of these had its disadvantages and difficulties. In counterbalancing a load by a conical drum, there was the difficulty that one cage was moving through a greater distance than the other cage at top and bottom of the pit, which was a great inconvenience for changing the tubs in cages of more than a single deck. There was indeed a mode of getting over this difficulty; but the difficulty itself was one which increased with the depth of the pit and with the greater amount of coning in the drum. In counterbalancing by the tail rope suspended under the cages, there was the disadvantage that a taper winding rope could not be employed. The weight was constant on the winding rope at any stage of the winding, and consequently a parallel rope was needed. But the use of a taper rope had great advantages for great depths. For example, a parallel steel rope 806 yards long, which was the depth of the Rosebridge Colliery, would carry only twice its own weight; at 580 yards, which was the depth of the Monkwearmouth Colliery, it would carry three times its own weight; at 433 yards (the example given at p. 328, of the Bestwood Colliery) four times its own weight. By a taper rope a much greater weight could be lifted in proportion to the weight of the rope used. The economical limit of depth, for the method of counterbalancing by a tail rope, would probably be found to be about 500 yards. In a paper by Mr. Daglish (Proceedings 1875, p. 217) a convenient unit was adopted for comparing the work done at different pits by different winding engines: it was the number of tons raised per hour per hundred yards depth, or multiplied by the depth in hundreds of yards. This was not an absolutely correct unit to use, because they might almost as well compare the mileage on one railway where the stations were frequent with that on another where the stations were far between, as compare pits of very varying depth by that rule. But he would compare the results at Bestwood with those at Sandwell Park Colliery, where the depth was almost the same. At Bestwood 586 tons per hour were stated to be raised per hundred yards depth; and at Sandwell Park 584 tons were

raised with the same size winding engines.* That was a strong corroboration of the author's figures for Bestwood. But Mr. Greig had given some figures showing apparently as much as 1400 tons raised per hour per hundred yards depth; and he should have been glad if the full particulars of that case had been furnished.

The most important points in quick winding were to get away from the pit bottom as quickly as possible, and to spend as short a time as possible in changing the cages. In order to get away quickly from the bottom, light cages were desirable, which could be best obtained by using steel. For the Sandwell Park Colliery he had supplied some steel cages which were only half the weight of the preceding iron cages; and the total saving in the weight to be shifted each time amounted to 17 per cent., which would of course quicken the winding. The construction of these cages was fully shown in Figs. 32 to 35, Plate 69.

With regard to the changing of cages quickly, a system to which he thought allusion should be made was Mr. George Fowler's plan of hydraulic loading and unloading. On this system, when a two-decked or three-decked cage was raised a certain height above the pit mouth, two dummy cages were raised alongside it by hydraulic power. One of these was ready charged with empty tubs, which

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* The leading particulars and dimensions of the winding gear at Sandwell Park Colliery are as follows (see also Proceedings 1876, pp. 330–2) :—

Engines—Pair of direct-acting horizontal, with cylinders 36 ins. diameter, 6 ft. stroke.

Depth of Pit—423 yards.

Drum—Slightly conical, from 18 ft. 9 ins. diam. at *largest working* part, to 18 ft. at *smallest working* part.

Rope—Parallel steel rope 4 in. circumference, not counterbalanced by tail rope.

Weight of rope suspended in shaft	28 cwt.
„ „ bridle chains and King's safety hook ...	15 „
„ „ steel cage	31 „
„ „ four iron tubs	28 „
„ „ coal in four tubs	50 „
Total weight to be lifted from bottom	152 cwt.

Weight of coal actually drawn during eight working hours—1100 tons.

were then, also by hydraulic power, pushed on to the winding cage, driving the loaded tubs before them on to the second dummy cage. Then away went the winding cage with the empty tubs, and while it was proceeding on its journey down the pit the second dummy cage was unloaded, and the first one charged with a relay of empty tubs; the same process being simultaneously carried on at the bottom of the pit shaft. This mode of working was shown in Fig. 36, Plate 70. AAA were the three empty-tub platforms, lifted up into position by the press ram R; BBB were the three unloading platforms, each on a level with one deck of the cage; they were lowered by the hydraulic press S, so as to withdraw the tubs one by one. The actual work of shoving the tubs off and on the cages was done by horizontal rams TT above the bank level, and by the ordinary banksman at the bank level. Thus the men usually required to change the upper tubs were saved. There was a further economy in the wear and tear of ropes, as more damage was done to the ropes by the repeated lifting of cages than by running in the shafts. At the Cinderhill Colliery of the Babbington Coal Company, near Nottingham, where he used to be engineer, this system was now in operation; and whereas about 30 seconds used to be occupied in the run and 30 seconds in changing the cages, now only 12 or 13 seconds were required for changing the cages, making that amount of saving in the total time. The same result might be obtained by means of a balance, without the hydraulic apparatus; but in that case the benefit would not be obtained of hydraulic rams to shove the tubs off the cages, and a man would be wanted for that purpose on each deck.

With regard to the most advantageous pressure for using compressed air, he wished to point out an erroneous statement in a translation made some years ago from a French journal, which he had seen quoted once or twice recently; and would do so in a subsequent note.*

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* The statement referred to occurs in the translation of a paper on "Work performed by Compressed Air" contributed to the 'Revue Universelle des Mines,' by M. L. Trasenster, Professor of Mining in the University of Liége, and will be found on pp. 60–62 of the English edition of that review for March, 1874.

Mr. M. Holroyd Smith wished to make a suggestion which was perhaps outside the province of engineers: namely that the prevention of colliery explosions might receive its final solution from the chemist rather than from the mechanical engineer. It seemed to him within the range of possibility to construct some chemical material, to be placed in the mine, that should absorb the fire-damp as it exuded into the workings. The absorbing power of charcoal,

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In calculating the ratio of the energy expended in compressing the air to the useful work theoretically given out, the translation remarks as follows:—

"The work given out soon reaches a limit which cannot be exceeded, whatever may be the pressure of the air, or the energy expended.

"The maximum of work given out (increasing the compression indefinitely, and without taking into consideration the elevation of temperature due to this compression) cannot exceed the energy given out by the volume of air caused by the piston of the blowing cylinder, working with an effective pressure of one atmosphere. This law is easily demonstrated.

Let p represent the pressure of the atmosphere;
P the pressure of the compressed air;
V and v their respective volumes;
Then $P = np$ or $V = nv$.

The work which this air is able to give out theoretically is

$$(P - p)\,v = P\,v - p\,v \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1.)$$

and as $P\,v = p\,V$, it follows that

$$P\,v - pv = p\,(V - v) = p\,V\left(1 - \frac{1}{n}\right).$$

As a cubic metre of air, subject to any given pressure whatever, can only give out a power equal to $p \times 1$, or 10333 kilogrammetres, when $\frac{1}{n} = 0$, or when n is infinite, so the same cubic metre of air, compressed only to two atmospheres, yields a force $T = 10333\,(1 - \frac{1}{2}) = \frac{1}{2} \times 10333$ kilogrammetres. The power which a cubic metre of air compressed to a million atmospheres is capable of yielding, without taking the rise of temperature into consideration, can never become double that which the same quantity of air compressed to two atmospheres is capable of yielding."

Now the expression (1), on which this result is founded, is only true if the air is used *without any expansion whatever*, as was generally the case with rock drills at the time the paper was written. This is distinctly specified in the original paper, but is omitted in the translation; and consequently the result has been quoted as if it were true of compressed air generally, which of course is not the case.

by which sewer gases could be absorbed, was well known. Was it not possible that some substance might be found with a special affinity for the explosive gas, and able to absorb it wherever it might be generated?

Mr. B. C. BROWNE thought a discussion on machinery used in mining should not be closed without a word being said as to the use of locomotive engines in mines, worked either by steam or by compressed air, especially the latter. There were now compressed-air locomotive engines working underground, and he believed they were doing good work and were an economical success. As it had been found that on the surface, generally speaking, locomotive engines had been able to hold their own against wire ropes, there was no reason to suppose that the same thing would not sooner or later happen underground. There were gentlemen present who had had practical experience of the matter, and he hoped it would not be passed over.

Mr. DAVEY, in reply, said that, as to the Kind-Chaudron system, he could not help thinking that wherever pumps could be got to work in any possible way the cost would be less; and that the Kind-Chaudron system should only be resorted to where the circumstances rendered pumping impossible.

In regard to the question raised by Mr. Greig as to the relative efficiency of hydraulic and compressed-air engines, he thought it could not be disputed that air engines were less efficient than hydraulic engines. He believed there was ample experience to prove this; and the statement that the ordinary efficiency of a compressed-air engine was from 25 to 33 per cent. was borne out by Mr. Daniel's paper (Proceedings 1874, p. 214). Very lately he had himself carried out some experiments which conclusively proved that high-pressure air, at all events, was not, and could not be, very efficient. With the same appliances there was as great a variation as 15 per cent. between the efficiency with low pressure and with high pressure, the difference being in favour of the low pressure. But compressed-air machines were very convenient, and

he had no doubt that in a very large number of cases, probably in the majority, the question of convenience outweighed that of efficiency; nevertheless as a scientific fact he did not think it could be maintained that air engines could approach hydraulic engines in efficiency.

Respecting the trip gear, Plate 63, upon which Mr. Cowper had remarked, he would take the opportunity of explaining that he had designed this trip gear especially for compound engines, for the simple reason that, if a compound engine was working against a load which might suddenly be taken off, and not only so, but might suddenly come to act on the other side of the piston, there was then an extreme condition of things which it was impossible to provide against by any ordinary appliance. During, say, the forward stroke, while the engine had still its normal load, the high-pressure cylinder took in a supply of high-pressure steam. Immediately on the reversal of the valve-gear this high-pressure steam was expanded into the low-pressure cylinder to produce the succeeding stroke: so that, if the load were then reversed, although the boiler steam might be cut off entirely in the steam pipe, yet there was already steam enough in the low-pressure cylinder, acting in the same direction with the load, to cause the engine to race, in spite of any amount of governing that might be applied to the main steam-valves. It was to meet this difficulty that the trip gear was designed.

He wished Mr. Walker had given a little more information as to the method employed for preventing the collapse of the flexible air-pipe, in the travelling crane he had spoken of. As far as he understood, the pipe was coiled round a drum, and formed the supply pipe from the air-compressor to the air engine. He should be glad to know how throttling was prevented in that pipe; for it seemed to him that, if there were several coils of pipe, one upon another, the pipe coiled underneath must be flattened, and that there must be an enormous loss through the throttling so occasioned.

The question of difficulty arising in blasting rock around the bore-hole shown in Fig. 7, Plate 61, had been raised by Mr. Lawrence, who had explained the method of prevention adopted at Whitburn. That method was obvious to himself, when he made the suggestion

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of putting down the bore-hole before sinking the shaft. Another very obvious method of preventing the choking up of the hole was to drop into the hole a liner much bigger than the pump : the liner would be simply a pipe, in lengths of 3 or 4 ft. ; it might even be made in segments, which could be taken off as the sinking progressed; but whilst in its place it would form a shield, and prevent any débris from getting into the bore-hole.

The suggestion as to boring a small pit and putting pumps in it, before commencing the main shaft, had been challenged by Mr. Lupton, for the reason that a very large shaft was required as an upcast shaft. In many cases he did not dispute that this was so. If the workings of a mine were so extensive as to require a very large shaft—and they would only become so extensive after a long time—it was perfectly feasible then to put down another shaft; but the water having been successfully dealt with in the first instance, this subsequent shaft could be put down at a minimum of expense. Further than that, when a colliery became so extensive as to require a very large upcast shaft, it was also so extensive that it required two winding shafts, one of which could then be made the upcast shaft. The merit or demerit of the suggestion of putting down a small pumping shaft beforehand turned entirely on the question of the total expense; and seeing that the water-bearing stratum did not usually extend to the whole depth of the pit, sometimes to not more than a third of the depth, the preliminary operation proposed for dealing with the water would be to bore a pit of half or a quarter the size of the main pit, and down to half or one-third of the depth. Although, in order to do this, the most expensive system—the Kind-Chaudron—might have to be used, yet this expensive system would be employed only on a small instead of on a large amount of work.

As regarded Mr. Walker's remarks on the failure of the fly-wheel, he was mistaken in assuming that it failed from faulty construction. It failed because, under certain conditions of working, it acquired a high speed from loss of load, and then, during the return stroke, having to encounter the load and the inertia of the great mass of pit-work, its momentum was spent on the arms,

which formed the connection between a *heavy revolving* and a *heavy reciprocating* mass. To couple a great revolving mass to a great reciprocating mass was a mechanical error. The inference which Mr. Walker apparently wished to draw was equally unfortunate. A fly-wheel was not necessary to economy in such a case. From the earliest days of the steam engine the direct-acting engine, as applied to heavy pit-work, had far surpassed all others in economy, and it did so at the present day.

ON A SINGLE-LEVER TESTING MACHINE.

BY MR. J. HARTLEY WICKSTEED, OF LEEDS.

The subject of Testing the strength of iron and steel under statical loads has received a very large amount of attention from the manufacturers and users of those materials, and from others interested in having a thorough knowledge of their mechanical properties. Numerous papers, giving the results of such tests, have been contributed to the Proceedings of this Institution, and of kindred societies; and it is therefore hoped that the description of a Testing Machine, now to be given, may not be without interest to the meeting. The writer does not propose to contribute a critical paper upon various makes of testing machines, but merely to give an accurate description of an individual machine; for which purpose however it will be useful to sketch beforehand some of the general considerations which have influenced the design.

Every dead-weight testing machine is in some form or other a weighing apparatus; and that which it weighs is the amount of resistance offered by the test sample to an attempt to distort it. The lines upon which a testing machine may be constructed are as various as the different well-known types of weighing machines; yet there are one or two essential differences between the conditions under which a dead load may be accurately weighed, and those under which the strains upon a test sample can be ascertained.

In the first place, a ponderable article counteracts the weights simply by its own gravity, leaving the weigh-beam free to oscillate until the balance is found; whereas a test sample, while having one end attached to the weigh-beam, must have the other end firmly held by an independent support. Hence care must be taken that no

unrecorded strain passes through the sample, such as might be due to shocks which with a free load would expend themselves in oscillations. Also, since the weigh-beam in the case of a testing machine is not, as in a weighing machine, free to be adjusted into the horizontal line regardless of time, it is important that the balance be "just" in all positions of the beam throughout its range of deviation from the horizontal line. The limits of deviation should be small; and as the sample is subject to extension during the testing process, provision must be made for moving the position of the independent support.

There is one form of weighing apparatus, viz. the hydrostatic, which leaves out of question the deviations of a weigh-beam; but there the inertia of the hydrostatic column and the friction of watertight joints introduce elements of uncertainty.

Probably the oldest form of weighing machine is the scale-beam or balance; and this, with the modification of having arms of unequal length, was the form of apparatus adopted in the well-known researches of Sir William Fairbairn and Messrs. Robert Napier and Sons. The machines used by both these experimenters consisted simply of a lever of the first order, to the short end of which was attached the sample, and to the long end a scale for holding the weights, which were added at discretion to test the resistance of the sample. In those primitive machines, the means for taking up the extension of the sample whilst under tension were not much considered.

In applying the principle of a scale beam for purposes of testing, it is very important to consider the element of "sensibility." An ordinary scale-beam is made in stable equilibrium; that is to say, the centre of gravity of the beam itself, while lying in the vertical line through the axis, yet falls below the point of support; so that when the beam is disturbed it tends to recover itself, the centre of gravity oscillating like a pendulum. The further the centre of gravity falls below the point of support, the more stable will be the equilibrium, and the smaller will be the range of oscillation of the beam, above or below the horizontal line, which can be permitted without vitiating the result; because, as soon as the beam leaves the horizontal line, some portion of its own weight has to be sustained

by the load. The nearer the centre of gravity approaches the point of support, the more "sensible" will be the beam, and the less will its own weight operate under a given disturbance. When the centre of gravity of the beam and all its rigid attachments actually coincides with the point of support, "indifferent" or "neutral" equilibrium is reached, and the balance of the beam is not affected by the number of degrees through which its inclination may range.*

It is obvious that the balance to be desired in the weighing apparatus of a testing machine is that of indifferent equilibrium; for thus the record of the machine is "just," whether taken when the lever is a little above or a little below the horizontal line.

The remaining type of weighing machine to notice is the steel-yard, in which the fulcrum and the loaded end of the lever are at a fixed distance apart, and a movable weight is made to travel to different distances from the fulcrum, so as to balance the load. The steel-yard in its simple form has been largely used for weighing from very early times; and more recently it has been employed, in conjunction with a further system of levers, for platform and pendant weighing-machines. This type, namely the steel-yard in conjunction with compound levers, has been largely applied to testing machines, and gives great compactness to machines of high power; but it is a question whether a heavy initial weight with a low power of leverage is not the most favourable condition to aim at. For testing moderate strains the writer prefers the steel-yard in the form of a single lever to any other form of weighing apparatus; and this is the type adopted in the 50-ton testing machine about to be described.

The novelties introduced into this steel-yard are the travelling of the weight beyond the fulcrum, on to the short end of the lever, till

* A balance may also be constructed with the centre of gravity of the beam above the point of support. Such a balance is in unstable equilibrium; and instead of oscillating, it tips over when not in perfect equipoise. It therefore requires supports for either end to rest upon alternately as it preponderates. This is the best form of machine for weighing letters &c., when the object is not to determine the precise weight of the article, but to ascertain with prompt decision whether it is more or less than a given standard.

a point is reached where the long end is balanced; the arrangement of a non-pendulous travelling weight, of which the centre of gravity moves along a centre line drawn through the point of support and the point of attachment of the sample; and the indifferent equilibrium of the whole, which is attained by arranging the weight of the lever and all its attachments symmetrically above and below this centre line. Referring to Figs. 1 and 2, Plates 71 and 72, A is a rigid cast-iron body having a projecting horn at the top, in which a hardened semicircular steel plate is fitted, which supports the main centre of the steel-yard. B is the main centre, which is made of a steel bar, brought to a knife-edge having an angle of about 90°, and hardened; it is carried between two side plates, which form the lever. This knife-edge for a 50-ton machine is upwards of 10 in. long, so that the pressure never exceeds 5 tons per inch of length. Within this limit a knife-edge of minute radius can be maintained; which is an important matter, seeing that as the lever oscillates the arc of the knife-edge rolls upon the supporting plate, and alters the mathematical position of the line of support. At three inches behind the main centre the inverted knife-edge C (shown enlarged, Fig. 4, Plate 72) is fitted through the lever; and from this are suspended the shackles D, which hold the sample S in the clips E. The main centre B of the machine and the back centre C being so close together, there is not room for the steel bars on which the knife edges are formed to be more than 3 inches in diameter; and this would not be sufficient to maintain the knife-edge, which is 10 in. long, in a rigidly straight line between the sides of the lever. In order therefore to prevent the knife-edges from yielding under pressure, there is a strong casting introduced, which embraces both about the middle of their length, and so upholds them one against the other, and also stiffens them to the sides of the lever.

The clips EE that hold a sample for tensile testing, Figs. 3 and 4, Plate 72, are parallel and serrated on their inner faces, and at the back are tapered to an incline of one in six. At this angle the clips are found to give the necessary bite, but loosen the hold when the strain is removed. At the back of the clips are half-round pieces TT, made free to revolve horizontally in the cast-steel clip-box, as shown

in plan, Fig. 3; by this arrangement the clips are enabled to swivel, and so can adjust themselves to bite fairly across a sample, even should it not be of truly rectangular section. The sample is similarly held by clips at its lower extremity; and the lower clip-box is attached to a bonnet K, Fig. 2, Plate 72, which screws on to the rod of a hydraulic piston F, shown in section, Fig. 5, Plate 71. This piston has a vertical motion of 6 in. in its cylinder, to allow for extension in the sample. Besides this, the bonnet K attached to the shackle can be screwed upon the piston-rod over a range of 6 in., to accommodate different lengths of samples. The hydraulic cylinder is firmly fixed to the lower part of the cast-iron body A. Water is forced into this cylinder either above or below the piston, by means of a piston of smaller area working in the horizontal cylinder G, shown in section, Fig. 6, Plate 71. This small piston is forced along its cylinder by means of twin screws, acting through a cross-head upon the piston-rod, and driven through gearing actuated either by hand or by power. Thus a perfectly steady motion is obtained. The annular area in front of the small piston bears the same ratio to the annular area on the top of the large one as exists between the whole areas of the two pistons. There is therefore continuous water from piston to piston on both sides, and the large piston responds at one-fifth the speed to every motion made by the small one. It will be understood that the hydraulic piston F, through its attachments, puts the required pull upon the test sample, and takes up the necessary extension: the other end of the sample is carried by attachments from the steel-yard, and, as the pull at each end of the sample is necessarily equal and opposite, it follows that the weighing apparatus balances and indicates the precise force with which the hydraulic apparatus is pulling.

The lever for thus weighing the pull has a one-ton weight W upon it, Figs. 1 & 2, Plates 71 & 72; this weight lies over the lever like a saddle, Fig. 2, Plate 72, and will travel from end to end of it. When the weight is at the short end of the lever, as shown in dotted lines in Fig. 1, it balances the long end; and the adjustable index finger I, Fig. 7, Plate 73, carried on the weight, is made to coincide with zero

on the fixed scale when the weight has reached a position which puts the lever and all its attachments into equipoise. The knife-edged centres being 3 in. apart, it follows that, after zero has been established at the balancing point, every 3 in. that the one-ton weight is traversed along the lever, as indicated on the scale, throws one ton of unbalanced load upon the test sample. The weight travels 150 in., or 50 times the distance between the centres, so that at the end of its travel it will balance a pull of 50 tons. Every 3 in. on the fixed scale is divided into tenths and half-tenths, so that with the index figure on the travelling weight the load can be read off to twentieths of a ton; *e.g.* 24·30, 24·35, 24·40 tons. There is moreover upon the index finger I a vernier scale, illustrated in Fig. 7, Plate 73, which again subdivides the half-tenths on the fixed scale into fifty, and gives thousandths of a ton: *e.g.* (in extension of the above readings) 24·301, 24·356, 24·409 tons. In this way an accurate result is read off down to 2·24 lbs. Thus, without the use of any small auxiliary weights, the most accurate results can be ascertained by the mere position of the heavy travelling weight upon the lever, and errors are reduced to a minimum; for there need be no more margin of error in a one-ton weight than in a 56 lb. weight; and here, with the extreme leverage of 50 to 1, that error can only be multiplied by 50, instead of by any higher multiplier. As the moving weight W is not hanging freely, but is carried on four wheels, it is kept rigidly in line with the lever; and as its centre of gravity coincides with the centre line of the lever, it follows that, however fast it is propelled or however suddenly its motion is arrested, the momentum can have no effect whatever upon the oscillations of the lever.

Motion is imparted to the travelling weight by a screw J, Fig. 1, Plate 71, passing along the lever between the side plates. The screw is driven by a belt from a small countershaft H, Fig. 2, Plate 72, bracketed out from the side of the lever, and the countershaft in its turn is driven by a belt from a pulley L running in supports on the main body A; but as the centre line through both spans of this belt lies in a vertical plane passing through the fulcrum of the lever, the pull upon the belt in no way affects the equilibrium of the lever.

The belt is driven either by a hand-wheel or from a lay shaft, as most convenient. The outer end of the lever oscillates in an opening through a vertical standard M, Fig. 1, in which it has a range of about 1° above and 1° below the horizontal line. In the bottom of the opening there is a thick block of wood, upon which the end of the lever falls, without undue jar, when the sample breaks. Throughout the whole of a test it is easy to keep the lever floating; for, owing to the low multiple of its power, its movement is slow. The aim is to avoid all vertical movement of the steel-yard, and thus to prevent any unrecorded augmentation of pull upon the sample, such as would be due to the momentum of a moving steel-yard.

Figs. 8 and 9, Plate 72, illustrate the apparatus which is put into the machine in lieu of the clip-boxes, for the purpose of testing strains in deflection; and Figs. 10 and 11, Plate 73, show a slight modification of the same apparatus for tests in compression. Fig. 12 shows a vertical scale N, Figs. 8 and 9, attached to the clips, which measures the extension, deflection &c. of the specimen.

In conclusion, it may be pointed out that in this machine there are only two knife-edged centres to maintain, so that the risk of impairing its accuracy on re-setting the knife-edges is minimised, as is also the number of edges to keep in order. Also the form of the machine is most favourable for verification, as it is only necessary to suspend ascertained weights from the short end of the lever, and to balance them with the sliding weight, in order to prove the accuracy at once of the weight, the scale, and the distance apart of the centres. The vertical arrangement of the machine is favourable to the life of the main centre, as there is no chatter of the knife-edge against the supporting plate when the sample breaks. It is not suggested that the vertical arrangement would be convenient for testing chain cables or very long samples: it is for the purpose of testing samples of iron and steel up to 2 ft. long, which comprises the great bulk of practical testing work, that this machine has been especially designed.

Abstract of Discussion on Single-Lever Testing Machine.

The President asked what was the author's opinion on the general question, how much pressure per inch of length should be sustained by the knife-edges. He might mention that the rule of 5 tons per inch length, mentioned in the paper, was also followed by Sir W. G. Armstrong & Co.

Mr. Charles Cochrane had had an opportunity of inspecting the machine on the previous day, and he was very much struck with its sensibility and delicacy. Another great point was the rapidity with which the work of testing was done by it; and in these days when almost everything, in wrought iron, steel, or cast iron, was required to be tested, diminution of labour in testing became essential. He knew nothing that would contribute more to that diminution of labour than the use of such a machine as this, which he understood would test twelve samples in an hour up to 50 tons.

Mr. Jeremiah Head could confirm all that Mr. Cochrane had said, and could also speak as to the very great improvement of this machine over its predecessor. Not that the machine formerly made by Messrs. Buckton did not test accurately—he did not suppose any greater accuracy could be obtained in practice than was obtained there; but a very practical feature of the present machine was the extraordinary rapidity with which it tested samples, as had been pointed out by Mr. Cochrane. Among the novelties of the machine, mentioned on p. 386, was not included the application of belt power to the machine, for moving the weight, and so on. Although belt power had been applied to some other machines, it had not been done so well and so practically as in the machine under consideration, which was eminently simple, accurate, quick, and handy in every respect. The only criticism he had to offer upon it was this. It was stated on page 387 that behind the tapered clips which held the sample there were semi-cylindrical blocks, which enabled the clips

to adjust themselves in a horizontal direction; but those who had often tested samples of that sort must have seen that when broken they were sometimes curved, showing that they had stretched a little more at one edge than at the other. He was therefore inclined to ask whether those blocks that had been described could not be made spherical, so as to allow them to adjust themselves to the sample not only sideways, but in any direction they liked.

Mr. R. PRICE WILLIAMS wished to bear his testimony, like the two previous speakers, to the value of the machine. He had been much struck with its exceeding accuracy. It was true that it was for a limited stress; and the only desire he had was that the author might apply the same ingenuity to testing machines on a larger scale. In some large testing machines minute calculations as to accuracy were involved, and disputes had consequently arisen respecting the results. But he thought anyone glancing at the testing machine now described must realise at once that its accuracy was perfect. He had seen it used, and what struck him perhaps more than anything else was the beautiful way in which the extension was taken up by the exceedingly ingenious device of the hydraulic cylinder, and the continuous motion that was thereby obtained, so that any extension was taken up immediately. He wished to make only one suggestion—that the author should add some means of recording mechanically, and without the need of callipers, the actual amount of extension.

Mr. JAMES KITSON, JUN., wished to ask the author whether he had had any experience in testing material held by a large pin through each end, instead of by the clip arrangement described on page 387. His own experience was that material, when tested in a machine where it was held by clips, would show a tensile strain of about five per cent. less than it would show if held by pins, so as to ensure the pull being exactly along the central line. The clip arrangement was a very ready system for works which had to test large numbers of samples; but it was not scientifically accurate, and for precise tests he should prefer the other system of fastening the sample.

Mr. David Greig considered that with material such as engineers were now using it was absolutely necessary that proper tests should be applied, so that makers might know they were using metal which would not give them trouble afterwards. Testing might be objected to by some manufacturers; but in reality it kept their workmen up to the mark, and was a protection against carelessness.

Mr. Daniel Adamson said this subject was very important in the way that Mr. Greig had put it—namely as to engineers being protected from the possible carelessness of manufacturers. But, more than that, the manufacturer wanted to be protected against the violent and bad usage of the material by the engineer. There was often more injury done by maltreatment than by defects in the material itself. In former times Sir William Fairbairn and others, who tested with the rudest of machines, got only half the data really necessary for the guidance of users. He was glad those days had gone by, and that more accurate appliances furnishing full information were now in general use. The author of the paper had correctly stated the fundamental principles involved in testing machines; but in his own opinion there was a great practical difference between the single-lever testing machine now described and the multiple-lever testing machine which was more commonly in use. Engineers were convinced of the necessity of basing their designs upon fixed and permanent mechanical principles, among which that of the lever was the most easily grasped and applied of all. If simplicity was a merit in testing machines, as indeed it was in all machines, then he thought the machine now described deserved the very highest place. But other conditions were necessary; and he could not take the view of it as a whole that had been expressed by some of the preceding speakers. Supposing the machine to be testing steel for bridge-work, which would carry say 50 tons per sq. in.; then the travelling weight would be run out to the far end of the lever, and he would assume that at that point, the maximum load being attained, the piece gradually broke. Now suppose a very accurate record were wanted of the extension &c. at that moment, it must be remembered that there would be the

inertia of a ton weight to overcome, or the momentum of the same weight to resist, as the lever ascended or descended through the height of the slot, in the standard that guided the outer end of the lever. In contradistinction to that arrangement he would take the case of his own multiple-lever testing machine multiplying one thousand times, which gave just twenty times the mechanical advantage of this single-lever machine. In the latter there was the ton weight passing through the limit of range at the end of the lever, say $2\frac{1}{2}$ in. or twenty eighths of an inch. With the multiple-lever machine of one thousand powers, on the other hand, presuming that all the levers were exactly in balance before commencing, there would be only the same range for the end of the registering lever when the weight was at its extremity, or $2\frac{1}{2}$ in. again. Now if a delicate test were wanted, was it more likely to be secured with a weight of 1 ton passing through $2\frac{1}{2}$ in., or with only 1 cwt. passing through the same space? So satisfied was he himself that the tests made with even the thousand-power machine did not give all which was wanted, that he was now constructing a machine with ten thousand powers. With the thousand-power machine there was still the vibration of the last lever to be got over, which showed the disturbance going on in the specimen; and that lever should therefore be actuated by a force the steadiest and most equable that could be arranged. Water was the steadiest means that could be used. He doubted whether it could be worked with a screw instead, without a good deal of torsional action, which was undesirable.

As to the speed of making tests, he had worked with a machine about thirteen years ago which took three and a half hours, with three men, to get a very moderate record of what was wanted. With the machine now described it was stated that twelve tests could be got per hour. He doubted whether this was not going too far in the other direction, because there ought to be time given to read off at every position of the specimen the facts that it was desired to note. Fifteen to sixteen minutes were required to test a specimen with the thousand-power machine, so as to secure a full and complete record from beginning to end.

He agreed with the author rather than with Mr. Kitson as to the grip-box being the best system for holding the sample: it gave greater accuracy in noting the commencement of permanent set &c., than when the sample was held by pins. In the latter case there would be what might be called a flow of force from the back of the pin, round the pin at the sides, and so forwards into the straight bar. The continuity of the metal was broken by the hole, so as to produce an undesirable want of uniformity in the strain within the next four or five inches' length beyond the pin. There might be an error in the grip-box occasionally; but he ventured to say that it would, in 95 per cent. of cases, enable a very uniform and accurate result to be registered, and would show that the metal had not been pulled unduly on one side or the other. If one flat bar were pulled in the testing machine by means of pins, and another by grip-boxes, each bar having previously been scribed on its surface, both lengthwise and crosswise, into square tenths or square hundredths of an inch, it would be found that, where the pin-holes broke the continuity of the lines of force, the outer side of the bar would be more punished than the inner, and the bar would be broken piece-meal, rather than as one whole. But with a grip-box the strain would be the same over the whole cross section of the bar. There was also another point in favour of the grip-box. When you had chopped a bar off in the smithy for testing, you did not want to have a great deal of boring and turning to do before it was ready; you wanted to take it just as you found it and pull it asunder. The grip-box would do that; and not only so with flat bars, but one of his own machines was daily in use pulling angle-irons asunder. Two-feet lengths were chopped off and pulled asunder with a system of angular wedges adapted to fit the grip-boxes, without any trouble to the manufacturer, who was abundantly satisfied when he saw that no trick could be played, as the piece was tested with its natural scale upon it. Since this system had been adopted, he had been told that prices of angle-irons varied with the quality of the material, as they ought to do. The purer metal, purer especially as regarded cinder, commanded a higher price—not however from its increased strength: for bad material, such as an imperfectly puddled bar with a great deal of

carbon and silicon, carried a much higher load than the purest iron, although from its hardness it lost both uniformity and ductility.

In the single-lever machine now described he had some slight objection to the arrangement of the lever, because it gave only 3 inches between the fulcrum and the attachment of the load, which was a small distance with heavy weights. In his own multiple-level machine that distance was nearer 6 inches: the first lever gave ten powers, and to it was attached a second of ten powers, and to this a third, all three being balanced; the three together thus gave a thousand powers, and the addition he was now making of a fourth lever would give ten thousand powers. There would still be the same range of $2\frac{1}{2}$ in. passed through by the end of the fourth lever, with only $11 \cdot 2$ lbs. upon it, in order to register the same 50 tons. Now certainly it would seem that with such a balanced system of levers, and with the same range of motion for the end of the last lever, the extension could be read off two hundred times as closely as with the single-lever machine. If simplicity was everything, the single-lever machine was the best; but if simplicity fell short of the refined and accurate registration of facts, then he thought recourse ought to be had to a more complete machine.

Was there any risk of getting out of truth with the more delicate machine? His own experience was the reverse. In the case of a system of levers, the multiple of the vibration was of course the same as the multiple of the power—that is, the long end of the thousand-power lever moved through a thousand times the space of the short end of the single lever. Hence there was such a long range to secure refinement and accuracy, that it must be very bad management which did not succeed in getting a very accurate registration. Was that high degree of accuracy needed? Having had some experience in testing, he might be allowed to mention his method. He generally tested on a sectional area of 1 square inch: that is, if the piece was round, its diameter would gauge a little more than $1\frac{1}{8}$ inch; and if it was square, each side was 1 inch. Now suppose a piece had to be tested of the purest possible iron: as to which experience had taught him that the maximum tensile load was about 19 tons per sq. in., and that it

contained 99·8 per cent. of metallic iron. When the stress approached the maximum load, the iron would extend considerably; and in a rude testing machine, having a large range in its lever, down would go the heavy weight to the bottom of the slot, with a tendency to overstrain and destroy the atomic resistance of the metal. That had always been the case with Fairbairn's old system; and there had never been an occasion when the breaking load on a reduced area had been registered by that method. He did not know whether he had himself been the first to pursue this part of the subject; but the high-power machines gave immense facilities for doing so, because with a thousand powers a disturbance of one thousandth of an inch in the sample was registered by a movement of one inch in the last lever. The lever told its own story, and it showed with the greatest accuracy what was going on. With a very ductile metal, it was needful to give it some amount of time to meet the strain, instead of tearing it right off; and then, as the high-power lever registered each successive elongation, there was an exact record of the percentage of elongation for each stress, beginning from the lowest. By the time the weight had been run gradually outwards along the lever (and it was astonishing how rapidly that work could be done, giving every record with a tabulated statement of pounds and tons) and the strain had been brought up to about $10\frac{1}{2}$ tons per sq. in., permanent set would have taken place; after which the load could be increased up to 19 tons—the maximum carrying power—with a registered elongation of from 18 to 22 per cent. in 10 in. of length. Was it not desirable that all these points should be exactly recorded? he held that it was indispensable. If any piece of metal were by accident strained to anything like the "breaking-down" load, it would be so disturbed that it could not carry the same load again, but would yield with a much less strain. The very pure iron now referred to, after carrying a maximum load of 19 tons, would carry less and less as the local or breaking elongation was developed: ultimately breaking down at $10\frac{1}{2}$ tons, or about the force which produced permanent set—a singular fact in the life and death as it were of the sample.

In using Bessemer metal the same law came into operation.

Bessemer iron or good mild steel was a compound of about 0·1 per cent. of carbon, 0·2 per cent. of manganese, 0·1 per cent. of undesirable alloys (as silicon, sulphur, and phosphorus), and 99·6 per cent. of iron. Such a metal possessed a tensile strength of nearly 30 tons per sq. in., with an ultimate elongation of about 30 per cent. in a length of 10 in. But 11 or 12 out of the 30 per cent. total elongation took place after it had carried its maximum load, and during its dying struggles: the reduction of sectional area being at the same time very great. This breaking elongation, as he had called it in his paper before the Iron and Steel Institute (Journal 1878, p. 383), was limited to a length of about four diameters; and it all took place after a general extension had gone on with moderate uniformity over the whole 10 inches' length of the sample. Of course it was deemed essential to have a record of these extensions: except in certain cases where there appeared to be a prejudice in the opposite direction. One such practical case was that of the guns made at Woolwich, where, with the view of securing strength, the practice was to temper the steel used, in oil; and no doubt a higher tensile strength was thus acquired. In Colonel Maitland's paper on the subject to the Iron and Steel Institute (Journal 1881, p. 434) it had been stated with regard to elongation that no special cognisance was taken of that point. But it was only by taking cognisance of the elongation that it became possible to judge as to the ductility of the metal. If by tempering in oil the metal acquired 15 per cent. more breaking strength, but lost 25 per cent. of its elongation—which latter he held was the measure of its ductility—then the value of that metal was really lessened, and not increased. Hence any system which neglected to take cognisance of ductility was what he had condemned ever since he had begun to investigate the subject four years ago; and he should never cease to condemn it until it was altered to a more rational one, such as would secure the best guns in the world for this country. That one example would show the necessity of very accurate testing.

In conclusion, he did not doubt that the single-lever machine described in the paper would give a very accurate test up to 50 tons. But this was not a limit of strain that he would himself recommend, because it did not reach the maximum tensile strength, say of a strong

bridge metal, which would carry from 50 to 60 tons per sq. in.; still less that of a piece of cast-steel to be used for tool or cutting purposes—and he was disposed to think that if more attention were paid to the composition and strength of such cast steel it would be a great advantage. Such steel possessed a higher limit of elasticity than the milder metals; but as soon as this was exceeded, it reached its maximum load almost immediately, broke down abruptly, and was done for. There were tool steels that ranged as high as a tensile strength of 70 tons per sq. in.—Sir Joseph Whitworth said 80 tons for his compressed steel; and therefore if the machine now described were made a little larger, engineers would find it more generally useful.

Mr. Benjamin Walker said that twenty years ago testing machines were comparatively unknown; the introduction of steel had been the means of bringing them into general use. He remembered an instance occurring twenty years ago of a large quantity of boiler plates, which were said to be not of a good quality. The ironmaster was sent for, and he said, "You are not using this properly; the iron is right enough, and if you used it properly, it would stand. I will undertake that if you get a plate of Low-Moor iron it will not stand that usage; if it will, I will take my iron back, and pay you a fair compensation." A great amount of trouble and cost, and a great waste of time, were thereby involved, which would have been entirely saved by the use of a testing machine. He fully agreed with Mr. Adamson that the multiple-lever machine, for mathematically accurate testing, was better than the single-lever machine; but he was persuaded that the single-lever machine was good enough for every-day practical purposes.

Mr. Arthur Paget drew attention to Mr. Kitson's remark that a system of free holding by pin attachments should be adopted for testing, and to Mr. Adamson's very antithetical remark that rigid holding by grip-boxes was the only possible system. He would ask both those gentlemen to consider whether each system had not its merits, the value of each depending entirely

upon the material which was being tested. If a rigid, inelastic, brittle material were being tested, free holding was absolutely esential to distribute the stress fairly over the sample to be tested. But in testing very ductile material, such as Mr. Adamson had spoken of as extending 25 per cent., it mattered very little whether the sample was held freely or rigidly, because the amount of extension would nearly equalise any inequality. Thus, if a piece of paper were pulled at one side, it could easily be torn across; but india-rubber might be pulled a great deal out of centre before attaining the same result. He hoped therefore that those who had such faith in their own systems would see that there was something to be said for the other side. Mr. Kitson had also told them that, from his experience, the difference in the mode of holding would make a difference of 5 per cent. in the strain which the material would stand, which was no doubt correct. He himself had recently made some small experiments on strips of steel of a very high quality and very thin, tempered to a good hard spring temper; and he found that, instead of 5 per cent., holding the strips too much on one side in some cases produced errors of over 50 per cent.

An objection had been raised by Mr. Adamson to the amount of motion in the far end of the lever. Again he would suggest—did not the extent of the objection depend upon the material to be tested? If the material was going to extend 25 per cent., as Mr. Adamson's material was able to do, did it really matter whether the extension were measured to an amount which might be reckoned in one decimal of an inch, or to an amount which might be reckoned in four decimals? Practically he thought the difference would be found quite immaterial. Mr. Adamson also doubted the truth of the statement that it was possible to test twelve samples an hour. Again he would point out that this depended upon what the samples were, and upon the amount of accuracy that was wanted. For practical shop use he thought there was no doubt that it was possible to test twelve samples per hour. For scientific experiments of great delicacy and accuracy, possibly that could not be done; but this machine was intended for testing materials as a practical every-day habit in the shops.

Mr. Druitt Halpin thought the machine now described an exceedingly accurate one; the only fault he had to find with it was its price, which would prevent it from being used as much as such machines ought to be used. The friction in this machine was very moderate, as he had seen it moved by a weight of $2\frac{1}{4}$ lbs.; but that was not an unparalleled result, as he had seen a 400-ton machine turned with a weight of 40 grammes (0·09 lb.) The chief objection which he had to all testing machines on this system was the very imperfect information which they gave. The author had referred to the possibility of floating the lever while the weight was moving outwards along it; but he had never seen that done perfectly, and he thought testing in that manner was very much like pretending to know what was going on in a steam engine by the initial pressure alone, without taking any account of expansion, condensation, or loss of any kind. But what was really wanted was a permanent record of all that was going on in the sample during the process of destruction; and this was done by a machine he had lately seen, quite as simple if not simpler than the one described in the paper. There was a complete diagram-recording apparatus attached to the machine; and the machine itself was worked with the town water-pressure, using an intensifier merely as a matter of convenience. The sample was put in, and torn; and a complete diagram was obtained of the work done in getting the extension at every point, showing also the limit of elasticity, the breaking load, and the whole behaviour of the sample right through the process. Mr. Adamson had spoken about time, as having an influence in testing. From the many thousands of tests which had been most accurately made in the machine he was referring to, it was proved that time, within any rational limit, was not of the slightest moment. Whether the specimen was broken in half an hour or in only three or four seconds, it was not possible with the most uniform material to detect the slightest difference in the diagram. With regard to the necessity for continued testings, he had had a case, only the week before, where a number of boiler-plates, made by a celebrated house, proved to have only one good quality, namely uniformity; they were sadly low in extension, contraction, and breaking stress. In an opposite case, a short time

ago, some material which appeared to the eye to be exceedingly bad was tested at University College, London, and gave most excellent results.

Mr. Wicksteed, in reply, said Mr. Head had called attention to the shape of the swivel backing pieces behind the clips, and had suggested that if they were made spherical their adjustment would be more complete. He thought he could answer that point, and also the point raised by Mr. Kitson and others, about holding by pins put through the sample. The latter plan was the old recognised method of holding samples, and it was useful in this respect :—if a machine were rudely constructed, and if the main knife-edge that formed the fulcrum of the machine were not truly horizontal, so that the shackles did not hang in a line perfectly normal to the knife-edge, then if the sample were held in rigid clips it would tend to tear in a curve. On the other hand, if it were held ever so roughly by a pin, it was practically loose in every direction, and it hardly mattered how much out of line the machine was, so far as arranging the sample went. Of course it induced slight inaccuracies, but none of much importance. By making the samples long enough, there was no doubt the strains were rendered tolerably uniform through the portion under observation, which was just that from one centre pop to another. But supposing that the knife-edge forming the main fulcrum was perfectly horizontal, that the centre line passed right along the line of motion of the pulling cylinder, and that the clip-boxes were all exactly in alignment with that centre line; and suppose a sample to be clipped rigidly by parallel serrated clips, which gripped it right across the face; then the consequence was that it was pulled precisely in parallel lines. It would be seen that it was impossible for one part of that sample to yield before another, because the knife-edge was parallel with the width of the sample, and also parallel with the joint pins of the links and shackles, so that the pull was maintained rigidly parallel in that direction, and if one side of the sample were weaker than the other, that weaker side would simply be relieved of a proportionate amount of the pull, until all the rest yielded to the same extent. Thus, so long as the knife-

edge was parallel with the width of the sample, and the pull was all in truth, the lines of action must be straight. If there were any want of parallelism in the sample itself—and they could not guarantee that it should always have its sides perfectly parallel in cross section—then the clips, if placed rigidly in a box, would clip the thicker edge only, and would tear that side, while the thinner side would not be doing its duty; but by putting the steel clips in front of half-round backing pieces which worked in a circular box, those backing pieces were free to adjust themselves in the box so as to close upon the sample fairly all across the face with a uniform bite. Thus it was impossible that the thicker edge of the sample could be severely gripped, without the clips swivelling round and closing tight upon the thinner edge also. There was nothing more to be done in that direction, he thought, by making the backing pieces spherical.

The President asked if the swivel-boxes were lubricated.

Mr. Wicksteed replied that the swivelling took place before any severe pull had come upon the sample; so that there was no need of lubrication. He might mention that it was an advantage to keep the clips short, in order that the bite should be decisive all across the sample; and although this made the teeth of the clips penetrate deeply in soft material, the samples showed no tendency to break within the clips, as the friction of the teeth prevented the metal from flowing freely, and thus contracting in area, within the bite. Doubtless a piece of tempered steel, as instanced by Mr. Paget, might be better held by pins, upon the ground that from its hardness it might partially resist the penetration of the teeth, so that a safe bite all across the sample would not be ensured.

Mr. Price Williams had spoken of the facility of testing the accuracy of the machine. That was a point which he himself considered of great importance. It was little good having a testing machine which itself required to be tested, as it were, by comparing its results with some other machine of acknowledged accuracy. It often happened that a result was called in question; and then similar

samples would have to be sent, to be tried in the two machines, and a repetition made, until people were satisfied that they were obtaining a correct result. But the present testing machine was one which could be proved against standard weights—not comparatively against some other machine. Being a vertical machine, it was only requisite to attach a suitable bar to the shackles, hang to it any number of 56-lb. weights, newly stamped so that their accuracy was assured, and then see whether, when the overhead weight had travelled to the mark which indicated that particular load, the two ends of the lever were in equipoise.

Mr. Adamson had brought in the element of time, in reference to the making of twelve tests in an hour. Time was an element which might be important in testing. For instance, a sample might be required to sustain a certain load for a certain period of time. That was not a common requirement in a test; and, as Mr. Halpin had said, it made little difference in the test itself. Ample time however could be taken when wanted; there was no difficulty in working slowly, but the reason that this machine was capable also of exceptionally rapid working was threefold. Firstly, there was the arrangement of the travelling weight with its centre of gravity following the centre line of the lever; under this condition, however rapidly it was propelled or however suddenly arrested, it could set up no oscillation and impart no vertical impulses to the lever. Secondly, there was the use of the steady hydraulic compressor, which could be worked at any desired speed without imparting anything of the nature of a blow through the column of water to the test piece. Thirdly, there was the low multiplying power of the lever, which caused its action to be slow enough to be controlled without difficulty, so as to keep it from bearing against the top or bottom bar of the slot in which the end of it worked. But these provisions for enabling quick working to be compatible with accurate results did not involve any necessity for working quickly; and where minute observations were required throughout all the stages of an experiment, the time spent upon a single test must of necessity be very much prolonged.

Now in following the comparison with a compound-lever machine, it must not be based on any difference in the rate of working. Take

the single-lever machine with 50 powers, and the multiple-lever machine of Mr. Adamson with 1000 powers; and suppose that the sample was being extended at a certain definite speed, which was the same in both machines, and that the lever was allowed to respond to the extensions of the sample. Suppose there was 1 ton weight at the end of the single lever, and that, owing to the rate at which the sample was being extended, this weight depressed the lever-end 1 inch in a second. With the multiple-lever machine, which had twenty times as much purchase, the sample still being drawn at the same rate, there would be 1 cwt. sinking at the speed of 20 inches in a second. Now it was according to one of the laws of falling bodies that the energy of 1 cwt. moving at the rate of 20 inches per second was 20 times the energy of 20 cwt. moving at the rate of 1 inch per second. Hence the unrecorded strain brought upon the sample in arresting a weight of 1 cwt., falling 20 inches in a second, was much greater than in arresting 1 ton falling 1 inch in a second; and this reasoning applied to every movement of the levers, whether upwards or downwards. But it was not well to look to the end of the lever for indications of the extension of the sample. The function of the lever was purely to counterbalance the pull of the hydraulic press. The press, and not the lever, took up the extension of the sample; and it was desirable that the lever should as far as possible be kept free from all vertical movement. Its indications would not separate the movement of the whole sample bodily, or of the parts outside the two pop marks, from the change in the distance apart of these two points on the sample, which alone it was desired to observe. To learn the extension of the sample between these two points, it was necessary to exclude reference to any fixed point outside them; and hence there was some difficulty in the attachment of a measuring apparatus, seeing that there were only two centre pop holes to attach it to, and even these were subject to elongation. An ideal apparatus would be purely optical: and that principle had been applied to some extent by the invention of Prof. Kennedy, who used a projected beam or ray of light; but even that apparatus, as far as it had been developed, required mechanical contact with the specimen.

The question of making a larger machine was simply one of cost. The 100-ton machines ran to a very large size, for the

simple reason that, no matter whether they had a single or a compound lever, they brought the full load finally on the one main knife-edge. That knife-edge, to be duly sensitive, must have 1 in. of length for each 5 tons of pressure; this was the rule which had been adopted by Sir William Armstrong in his accurate machines for testing chain-cables, and it was looked upon by himself as being a rule recognised by the highest authorities. Hence a legitimate 50-ton machine required for its main fulcrum a knife-edge upwards of 10 inches long, and a legitimate 100-ton machine required a knife-edge 20 inches long, which must be perfectly true and hard and preserved from flexure. The size of the machine was a question of requirement; and although there was steel which bore a tensile stress of 55 or 60 tons per sq. in., machines were not in great demand for testing to so high a strain. The demand was for a machine that would test samples which never exceeded 50 tons per sq. in. As to the fancy materials, like silver-steel and so on, tests of these were not in practical demand, and therefore it was not generally thought worth while to have so ponderous a machine as would be called for by them.

With regard to the difficulty in the floating of the lever end, which Mr. Halpin had alluded to, the slot in the standard was not deep, so that the lever could not vibrate more than one degree above or below the horizontal line. Hence the pull was always almost normal to the centre line of the lever. But if the lever were wanted to float, it was only needful to give a little more depth to the slot, so as to allow more latitude for floating. There were great facilities however for floating this lever. Its movement was slow; and, on the other hand, the power motion applied to the travelling weight gave the command of a very quick motion for its adjustment. The speed of this motion was kept in check by merely placing the hand upon a small hand-wheel; by regulating the pressure of the hand the motion could be arrested, slowed, or set free. The scale on the travelling weight pushed in front of it a small marker, which remained to record the point of maximum load attained: and as soon as the sample failed to support this load, the motion of the travelling weight was reversed, and the weight was run back upon the lever, so as still to be a counterpoise to the pull. Thus the position of the

weight at the end of the experiment would be that due to the breaking strength of the reduced area of the sample.

With regard to the diagram-recording apparatus, he hoped there would be an opportunity of hearing more about it. It was a thing that was much wanted, and he had no doubt it would be as applicable to one testing machine as to another. In the meantime the ordinary method of taking successive observations with dividers and calipers, and plotting the results upon a card, was extremely reliable, and could be carried out with microscopic accuracy.

Finally he might say that he had had the pleasure of showing one of these machines to several members, just as it stood for the temporary purpose of being viewed. It was opposite large open doors, and various disturbing conditions affected it; yet they had seen, even with off-hand adjustment, that $2\frac{1}{4}$ lb. on the short end would sway the beam; and he might state that, when properly placed and with a little time for careful adjustment, he had found no difficulty in poising the machine so that a 2-oz. weight on the short end would turn the balance. Since, in this machine, the initial pressure upon the knife-edged fulcrum, due to the weight of the lever and the 1-ton weight, was increased only about 25 times under the maximum strain of 50 tons, it might be assumed that the 2 oz., required to produce motion when the machine was free, would not be unduly magnified when it was under its full strain: and it should be borne in mind that the useful sensibility of a machine for testing the strength of metal was not to be computed so much by the degree of sensibility that might obtain in measuring the pull of a horse-hair, as by the degree which it could be shown to retain when measuring its maximum load.

The President, in moving a vote of thanks to Mr. Wicksteed, remarked that he had given in his paper a description of a thoroughly well-considered piece of mechanism; and ought to be congratulated upon its success, and also upon the very able manner in which he had replied to the friendly criticisms that had been made.

ON GOVERNING ENGINES BY REGULATING THE EXPANSION.

By Mr. WILSON HARTNELL, of Leeds.

The object of the present paper is to illustrate the advantage of Automatic Expansion Gear: in other words, of controlling the expansion gear by means of the governor; and to describe two such methods which have been arranged by the writer, and which have been extensively used, chiefly for small steam-engines.

Advantages of Automatic Expansion Gear.

The chief advantages derived from automatic expansion gear are, firstly, the saving of fuel arising from the smaller consumption of steam, and secondly, the greater regularity of speed.

Economy of Steam.

Saving of fuel.—The extent of this saving depends upon the particular circumstances of the case. If the engine be for the most part fully loaded, expansion gear is of little benefit. If the steam pressure and the load be at all times nearly constant, expansion gear variable by hand may be equally advantageous.

Non-automatic expansion gear must be adjusted to cut off late enough for the maximum load with the lowest pressure, otherwise the engine is liable to be stopped instead of regulated. Hence for engines subject to very variable loads, such as ordinary agricultural engines, expansion-gear variable by hand is practically useless. It is well known that, when a non-expansive non-condensing engine is working with a light load, the fuel used is excessive in proportion to the net HP. expended, the work of the steam being spent principally in overcoming the atmospheric resistance. The saving in fuel

therefore, due to automatic expansion, will be greatest in non-condensing engines with very variable loads, for the most part lightly loaded. In portable engines with automatic expansion the saving of fuel and water has been frequently reported by the users to be as much as one-third, when compared with an ordinary engine under the same average conditions.

Estimate of the steam saved.—Since the economy effected by automatic expansion is a variable quantity, depending upon the range of variation in the load as well as upon the particular construction of the engine and boiler, it is better here to omit reference to the fuel. The measurement of the economy of steam, and the manner in which it arises, may be most readily shown by reasoning deductively from definite hypothetical conditions of load, and from assumed relations in regard to the point of cut-off; these relations agreeing with experiment on good average engines.

Throughout this paper the writer has illustrated the various relations discussed by means of geometrical diagrams, without giving the demonstrations; firstly as being the clearest and simplest means, and secondly because many of the investigations thus illustrated would occupy more space than the whole of this paper.

Form of indicator diagrams.—Figs. 1 and 2, Plate 74, are hypothetical indicator diagrams, showing the cut-off at 20, 40, and 60 per cent. of the stroke, with single and double valves respectively, in condensing and non-condensing engines. Fig. 3 shows the effects of throttling. These diagrams are drawn in accordance with actual indicator diagrams, the initial pressure being assumed at 60 lbs. per sq. in.

Economy of steam with various periods of cut-off.—The vertical ordinates drawn to the curved lines in Fig. 4, Plate 74, show the water used per I.H.P. per hour for a cut-off at any part of the stroke, the lines being drawn in accordance with experimental data and with Figs. 1 and 2. The lines 1 and 2 are for condensing engines, and 1*a* and 2*a* for non-condensing engines.

Economy of steam under a variable load.—Fig. 5, Plate 74, shows the relation between the quantity of steam expended and the mean pressure on the piston, using the throttle-valve and the expansion-valve respectively, in non-condensing engines, corresponding with the diagrams in Figs. 3 and 2. The ordinates of the line A B represent the mean pressure on the piston, for the different points of cut-off, and the ordinates of the curved lines C D and E F the comparative steam used with the throttle-valve or the expansion-valve. The vertical distance between the curved lines shows the extra steam used with throttling as against expanding, at the corresponding mean pressure. Fig. 5 may be constructed from real indicator diagrams, by drawing curves to represent the final cylinder pressures that correspond with the observed mean pressures, and making allowance for compression, condensation, &c.

Economy of steam with any given variable load.—This is illustrated by Fig. 6, Plate 74. The horizontal distances between the vertical lines represent intervals of time. The height of any ordinate to the full curve represents the mean pressure on the piston at the corresponding time. The dotted curves are plotted from Fig. 5, at heights corresponding with the respective mean pressures. Hence the space enclosed between the full curve, the base line, and any two ordinates, represents the relative work done in that interval of time; and the spaces enclosed by the same ordinates and by one of the two dotted curves represent the relative quantities of steam used, when regulating with the expansion valve and with the throttle-valve respectively. The space between the dotted curves represents the steam saved by expanding instead of throttling.

Regularity of Speed.

Prompt governing. — The promptness with which automatic expansion gear controls the engine, as compared with a throttle-valve, is owing to its freedom from two evils, which may be termed "retardation from storage" and "retardation from friction."

The retardation from storage is the effect due to the steam that is stored between the throttle-valve and the steam-port. The retardation from friction is the effect due to the friction of the throttle-valve, or of the controlling gear.

With a cut-off valve there is no storage, if it be a main slide-valve or a valve on the back of the main valve. With a cut-off gear there is also little or no friction to be overcome by the governor; for the reciprocation itself tends to move the gear in opposite directions alternately, so that the governor has merely to hold it still, or else permit it to move itself.

Relation between position of governor, speed of engine, and pressure on piston.—These three quantities have a definite relation, if the boiler pressure be uniform. For the mean pressure depends upon the position of the cut-off gear or throttle-valve, which position depends upon the speed of the engine. This is illustrated in Figs. 7, 8, 11, and 12, Plate 75, by three series of lines, which may be called governor lines, speed lines, and power lines. Thus in Fig. 7 the speed line, when coinciding with line No. 3, is supposed to correspond with the position of the governor shown by the governor line corresponding with line No. 3, and also with the mean pressure or power shown by the dotted power line corresponding with line No. 3. If the speed falls to line 4, or rises to line 2, the corresponding positions of the governor line and of the dotted power line will be the lines 4 or 2.

Perfect governing.—Perfect governing with automatic expansion gear is illustrated by Fig. 7, Plate 75. The full line on the lowest third of the diagram indicates the load, that is, the mean pressure on the piston which would exactly balance the load: this may be called the independent variable. The dotted power-iine running beside it shows the actual mean pressure on the piston, or the power. It is obvious that the spaces enclosed between the zero line and the load line, and between the zero line and the power line, will on the average be equal to each other, as illustrated by the horizontally and vertically

shaded spaces. When the load is in excess, the speed and the position of the governor will fall. When the power is in excess, the speed and the position of the governor will rise. The diagram is merely illustrative, and not quantitative. Thus the load is supposed to rise suddenly from 3 to 4, and simultaneously the speed of the engine, the position of the governor, and the mean pressure on the piston begin to vary, until the power rises to balance the load. The speed then remains uniform, but rather slower. This is shown by all the lines changing to position 4, and remaining there. The horizontally shaded space represents the power given out by the fly-wheel. Further on the load is supposed to fall to 2, and the speed to rise to 2. The vertically shaded space then represents the power absorbed by the fly-wheel.

Retardation from storage.—This is illustrated by Fig. 8, Plate 75. The load is supposed to vary from 2 to 4. The speed line falls from 2 to 4, and the governor line does the same; but owing to the storage the mean pressure or power line does not simultaneously rise to line 4. The speed therefore continues to fall, say to line 5, and the governor, instead of remaining at position 4, falls to position 5, thus putting on too much steam. The speed will then begin to rise again until too much steam is shut off; and in consequence several oscillations of speed take place without any further change in the load.

Retardation from friction.—Fig. 9, Plate 76, shows the outline of a pendulum governor with balls 5 in. diameter, about the size usual in an 8-HP. engine. Fig. 10 shows the speed due to the balance of the centripetal and centrifugal forces, and to the effect of friction. Here A R_1 and A R_2 are the minimum and maximum radii of the governor balls. The centripetal curve $C_1 C_3 C\, C_2$ is drawn so that any vertical ordinate R C equals the centripetal force at radius A R (say in lbs. to any convenient scale), due to the weight of the balls. The vertical ordinate drawn from R_2 to 60 represents the centrifugal force at radius A R_2 and at a speed of 60 revolutions per minute. Since

the centrifugal force due to 60 revolutions per minute varies as the radius,* any vertical ordinate to the line drawn from A to 60 will equal the centrifugal force at that radius due to that speed of 60 revolutions per minute. In like manner the other divergent lines indicate the centrifugal forces shown by the respective speeds figured on the ordinate at R_2. Let the point C be the intersection of the centripetal curve by any radial line, say that for 60 revolutions. Then R C is both the centripetal force at radius A R and the centrifugal force at the speed (*i.e.* revolutions per minute) figured on that radial line. This speed is that which would support the ball at radius A R. The speed that would be indicated on the scale by a line drawn from A through any point C may be called "the speed due to point C."

The friction curves $F_1F_3F\ F_2$ and $G_1G_3\ G\ G_2$ are drawn by measuring C F equal to the friction to be overcome to move the balls outwards at any radius A R, and C G equal to that to be overcome to move the balls inwards.

The speed due to the point F is that to which the governor must rise before the balls can move outwards from radius A R, because R F is the centripetal force to be overcome. Similarly G indicates the speed to which it must fall before the ball can move inwards from that radius; because R G is the centripetal force pulling the balls inwards. For intermediate speeds at that radius, the radial distance of the balls will remain unaltered.

If the governor balls range from R to R_3 under variations of load, the variations of speed will be those indicated by the curves F F_3 and G G_3, instead of C C_3; and however slight the variations of load at radius A R, the speed cannot vary less than indicated by the points F and G.

If the radius be taken in feet, the area of the quadrilateral

* For if n be the rev. per min., then the lineal velocity per second is $\frac{2\pi r n}{60}$; and the centrifugal force $= \frac{(\text{velocity})^2}{r} = \left(\frac{2\pi n}{60}\right)^2 \times r$.

C_3F_3 F C (measured by the horizontal width and mean vertical height to the respective scales) gives the work done by the governor in overcoming friction while opening from radius A R_3 to A R; and similarly the area C G G_3C_3 gives the work done in closing from A R to A R_3. Similarly the area $C_1F_1F_2C_2$ gives in foot-pounds (measured as above) the work done by the governor in moving outwards through its entire range; and $C_1G_1G_2C_2$ the same on its return inwards. These areas will probably not be equal, unless the connections to the throttle-valve are balanced. Nor will the vertical lines C F, C_3F_3, &c. be usually equal. The area $R_1C_1C_2R_2$, enclosed between the centripetal curve C_1C_2 and the base line R_1R_2, shows the work done to open the balls in lifting the governor weights, or compressing the spring in a spring governor. This may be described as the *governor power*. The "sensitiveness" of the governor is here taken to mean the ratio per cent. which the difference between the speeds indicated by the points C_1C_2 bears to their sum. Thus, if S_1 and S_2 be those speeds, V = the sensitiveness, $V = 100 \left(\frac{S_2 - S_1}{S_2 + S_1}\right)$.

The "retarded sensitiveness" here means the sensitiveness under friction, or a similar percentage taken for the speeds given by the positions of the points G_1 and F_2.

The difference between the speeds due to the points F and G, measured as a percentage of the mean speed, may be called the "detention" at radius A R.

Under the conditions of ordinary practice, whatever be the form of centrifugal governor for which such a diagram as Fig. 10 is drawn, it will much resemble this figure in form. The speeds due to the points G, C, F will vary as the square roots of the ordinates R G, R C, R F. If the friction be comparatively small, the "detention" at radius A R will be nearly $100 \times \frac{\frac{1}{2} \text{F G}}{\text{C R}}$, which will be about the same as $100 \times \frac{\frac{1}{2}\text{area of } G_1F_1F_2G_2}{\text{area of } R_1C_1C_2R_2}$; or in general, the detention, with all forms of centrifugal governors, will be equal or nearly equal to 100 times the mean friction to be overcome in traversing from R_1

to R_2 divided by the governor power (both measured in foot-pounds).*

Governor Power.—Whatever the difference of construction between any two good centrifugal governors, still, if they are of equal power, the "detention" will be the same; and if they are equally sensitive, the "retarded sensitiveness" will be the same: thus the governors will be about equally efficient. Otherwise the one with most governor power will govern best. In the above example the sensitiveness is about 5 per cent. from the mean. If the mean friction of the throttle-valve be 3 per cent. of the governor power, the detention will be 3 per cent., and the retarded sensitiveness will be $5 + 1\frac{1}{2} = 6\frac{1}{2}$ per cent.

In order to be ample, the governor power should be say 20 times the friction to be overcome; it may be 40 times with advantage. The description of any governor should state its free variation and its power. For example, the governor shown in Fig. 9, Plate 76, with 5-in. balls at $8\frac{1}{3}$ in. maximum radius, allows 6 per cent. variation from the mean speed, and its power is $5 \cdot 6$ ft.-lbs. It may be shown from Fig. 10, Plate 76, and Fig. 28, Plate 77, that as the friction curve is raised the governor begins to be unstable, commencing at the least radius. This would cause continuous "hunting," the balls flying out

* Let G = governor power in ft.-lbs. (represented by area $R_1C_1C_2R_2$ on Fig. 10).
,, F_1 = frictional work (in ft.-lbs.) to be done whilst the governor balls traverse from R_1 to R_2 (represented by the area $C_1F_1F_2C_2$ on Fig. 10).
,, F_2 = ,, ,, ,, R_2 to R_1 (or area $C_2G_2G_1C_1$).
,, Y = the detention at any point C.
,, V_1 = the sensitiveness.
,, V_2 = the retarded sensitiveness.

$$100\left(\frac{F_1 + F_2}{2\,G}\right) = \text{nearly the mean value of } Y\text{, say } Y_m.$$

$$V_2 = V_1 + \frac{Y_m}{2} \text{ nearly.}$$

$$\text{or } V_2 = 100\left\{\frac{S_2 - S_1}{S_2 + S_1} + \frac{F_1 + F_2}{4\,G}\right\} \text{ nearly.}$$

and returning slowly. The more sensitive the governor, the more possible is such an occurrence.

Retardation from friction.—The effect of this is to oblige the engine to change its speed sufficiently to overcome the friction every time the load is in the least changed, as shown in Fig. 11, Plate 75. The load increasing from 2 to 3, the speed falls to 3 before the governor commences to move, and falls say to 4 before the governor has fallen to 3. The increase of load again being taken off, the speed makes a large excursion in the opposite direction.

Retardation from storage and friction combined.—The total variations of speed, arising from the combined retardation from storage and from friction, are much greater than either separately. They are illustrated in Fig. 12, Plate 75, where the load is supposed to increase from 3 to 4, and to remain constant. The governor, owing to the friction, does not begin to fall until the speed has fallen to 4; and when it does fall, the power line is not sufficiently changed till a little later. In consequence the speed continues to fall still more, and too much steam is admitted. The mean pressure thus continues to rise, and produces an opposite variation before the governor begins to go in the opposite direction. Thus one small variation of the load may produce a series of disturbances in the speed, although there be no further variation in the load. These effects may be noticed in an exaggerated form in a compound engine, where the governor works stiffly. By comparing Fig. 7 with Fig. 12, the immense advantage of governing the cut-off gear will be apparent. It is however but just to state that the same effect could be produced with the throttle-valve, if friction were a very small fraction of the governor power, and if storage could be got rid of.

Special Automatic Expansion Gear.

The writer will now describe two arrangements of automatic expansion gear which he has devised, and which have been extensively and successfully used for some years.

The governor shown in Figs. 13 and 14, Plate 78, and also in

Figs. 18 to 21, Plates 79 and 80, is fixed to the crank shaft, and was schemed especially for portable engines. Its design resulted from the following considerations :—(1) that very great governor power (several hundred ft.-lbs.) could be obtained by placing the governor in the fly-wheel; (2) that with so much power it would be easy to move the eccentric, and by some form of wedge gear to hold it when moved. It was afterwards found that sufficient power could be obtained in a much smaller diameter than that of the fly-wheel; and separate governor-drums were then adopted as more convenient.

Form applied to a separate cut-off valve.—Figs. 13 and 14, Plate 78, represent this governor as applied to the cut-off eccentric of a fixed engine. It consists of a drum A, and weights BB, swivelling on the weight-pins C C. The weights are connected by the coupling-rod D, which is acted upon by the spring E. The eccentric F has play upon the shaft, as shown in Fig. 14 and also in Fig. 15, Plate 77, but is solid with the eccentric-carrier G, swivelling on the eccentric-pin H. The governor is coupled to the eccentric-carrier by means of a curved solid link I called a quadrant (although really less than a quarter of a circle), which is fixed to the quadrant arm K, and works through a slot in the quadrant-pin J on the eccentric-carrier G. The quadrant is placed oblique to the circular path it describes round the centre C, thus acting as a wedge; so that by its intervention the governor can move the eccentric, but the eccentric, acting nearly at right angles to the wedge, cannot move the governor. It will be noticed that the eccentric and the weights are guided in circular paths by pins, and not in straight lines by slides; thus reducing friction to a minimum, and so ensuring greater delicacy of action.

The resistance of the valve may be considered as a force acting on the centre of the eccentric, as shown in Fig. 15, Plate 77, and tending alternately to push it towards and pull it from the centre of the shaft during each semi-revolution. Thus the power required to shift the eccentric is obtained from the crank-shaft, and not from the governor. The incline of the link, and the other moving surfaces, are so proportioned that the friction produced by the resistance of the valve equals, as nearly as possible, the pressure tending to alter the

throw of the eccentric. Thus the governor has little or nothing to do in order to hold the eccentric in place; and freely adjusts it at such times as the governor and the eccentric are acting in the same direction.

The cut-off valve used may have single ports; but to reduce the travel of the eccentric, multiple ports have been generally used, as shown in Fig. 16, and especially in Fig. 17, Plate 76. (See Note A, at end, page 425.)

Governor applied to ordinary slide-valves.—With small engines, say with less than 10-in. cylinders, it has been preferred for the sake of simplicity to use but one slide-valve. The governor was at first placed in the fly-wheel. It is now generally placed in a separate drum, attached to an eccentric which is coupled direct to the valve-rod. Fig. 18, Plate 79, shows the interior of the governor as used for an 8-HP. or 10-HP. portable engine, with the weights open and the eccentric in mid gear; Fig. 19 shows the weights closed and the eccentric in full gear; Fig. 20 is a sectional plan. The drum is confined to 18 in. diameter, in order to clear the boiler. The parts have been arranged to use all the available space. The construction is essentially the same as in Fig. 13, but the quadrant can be set oblique in either direction, in order to reverse the engine. As before, A is the drum in three pieces, namely the disc-plate, which is keyed to the shaft and turned on both sides to carry all the working parts, and the casing in halves; B B are the weights, C C their pins, D the coupling rod, E E the two springs, F the eccentric, G the eccentric-carrier, H its pin, I the quadrant, J the quadrant-pin, K the quadrant-arm. The eccentric F being outside the drum A, while the eccentric-carrier G is inside, the two are here fixed together by three stud-bolts S, which work through slots in the disc-plate of the drum, as shown in Fig. 20, these slots being struck from the centre-pin H of the carrier G. In Figs. 18 and 19 the disc-plate of the drum is supposed to be transparent. The outer extremity of the quadrant I is pivoted in a prolongation of the weight B which carries it, as seen at L in Fig. 19. The path of the centre of the eccentric from full gear forward to full

gear backward is a circular arc struck from the centre-pin H. When the weights are closed, Fig. 19, the engine being at rest, the quadrant I puts the eccentric in mid gear (*i.e.* opposite the crank-pin of the engine). In this position the quadrant-pivot L is nearly concentric with the carrier-pin H. The other end of the quadrant is held by a screw N. Suppose the quadrant set obliquely, to run the engine forward. Then, to reverse the engine, set the piston near the end of its stroke, insert a strong screw-driver through the open part of the eccentric, slacken the screw N, push the eccentric across, and tighten the screw again.

This form of governor was first used at the Cardiff engine-trials ten years ago, and was immediately adopted by Messrs. E. R. & F. Turner, for their 8-HP. portable engines; from that time uninterruptedly until now the throttle-valve has been abolished in their 8-HP. engines. So far as the writer is aware, from that date it is the only automatic gear which has been thus used for portable engines, to the entire exclusion of the throttle-valve; or which is even so used at the present day. With this governor it is difficult to detect any variation of speed under the most rapid and frequent changes of load. The supply of steam seems to vary simultaneously with the change of load. After a few governors had been made on the Cardiff pattern, it was found that larger wearing surfaces and more accurate work were desirable. The form of the drum was altered to that shown, in order to facilitate the application of machine work. The bearing surfaces were enlarged, and the adjustment fitted to the quadrant-pin; retaining however almost the identical centre lines. Some of these earlier governors were replaced; as were also the piston-valves, shown at Cardiff, by ordinary slide-valves. So far as the writer is aware, with the above exceptions the governor has been uniformly satisfactory; and he anticipates that automatic expansion governors fixed on the crank-shaft will in future be more used for small engines than any other kind of governor.

Another form of this governor is shown in Figs. 21 & 21*a*, Plate 80. A is the drum, BB the weights, CC very large centre-pins cast on the weights, D the coupling rod, E E the springs, F the eccentric fixed on the coupling rod D. Although the friction of the pins C

cannot hold the whole thrust of the eccentric, yet with quick-running engines the governor works well with the ordinary slide-valve. Being simple and inexpensive it is being applied to such engines, including the cheapest forms, without increasing their cost. It can be reversed by attaching the coupling rod D to the opposite side of the axes of the weights. Thus by means of governors placed on the crank-shaft and acting on the eccentric, throttle-valves may be abolished, and the advantages of being governed by regulation of the cut-off may be obtained in all sizes of ordinary engines.

Automatic Expansion Regulator.—A governor and expansion gear not fixed on the crank-shaft, and therefore called for distinction by the above name, is shown in Figs. 22 to 24, Plate 78. Here A is the body casting, B B the weights swivelling on the pins C C, D the slide, E the spring, F F two rollers which press on the slide. This was designed as a simple compact automatic expansion gear suitable for small engines. It is capable of any required degree of sensitiveness, and so powerful that it readily controls the expansion gear. The form of slide-valve used may be the same as in Figs. 16 and 17, Plate 76. That shown in Fig. 17 has been chiefly used for large engines. The cut-off is varied by means of the link gear shown in Fig. 22, which has been arranged so that, with a mean load, the eccentric-rod and valve-rod are in line, and there is little or no slip on the block. The whole is hung on the governor stand. The maximum incline of the link should not exceed 1 in 6.

Governor power obtained with springs.—This is much greater than can be obtained by the action of gravity in the same space. (See note B, page 425.) Fig. 9, Plate 76, shows an outline of a pendulum governor for an 8-HP. engine, and Fig. 25, Plate 76, shows that of the 8-HP. automatic expansion regulator to the same scale. The power of the former is 5·6 ft.-lbs., and that of the latter 37·2 ft.-lbs. The dotted circle, Fig. 25, shows the diameter of ball which, being raised the same height as the spring, will give an equal power. Fig. 26 shows a regulator for a 50-HP. engine with double springs; its governor power is 270 ft.-lbs. Comparing Figs. 9 and 25, both for the 8-HP. engine, the spring governor is six times more powerful.

The most advantageous travel for the balls may be shown to be half the maximum radius. (See Note C, page 426.) The large governor, Fig. 26, is of unusual power. The expansion governor used at the Cardiff trials had about 90 ft.-lbs. governor power. The usual power for an 8-HP. engine is about 50 ft.-lbs.

Sensitiveness.—In this design the sensitiveness, or the variation from the mean speed required to traverse the governor, can be varied as desired. About 4 per cent. from the mean speed has been found best for small engines, and 3 per cent. for large ones. The size of the fly-wheel must be such that the variation of speed from the main in each semi-revolution is less than half the sensitiveness of the governor. (See Note D, page 427.) Suppose for the sake of simplicity that the arms B C, C F of the bell-crank levers in Fig. 23, Plate 78, are equal and at right angles; then in all positions the vertical compression of the spring equals the radial movement of the balls.

Let us suppose that the mean speed is 100 revolutions per minute, and the sensitiveness 5 per cent. Let Fig. 27, Plate 77, be a diagram drawn in the same manner as Fig. 10, Plate 76. The centripetal line with a right-angled bell-crank will evidently be a straight line. Draw this centripetal line C_2C_1, and produce it until it meets the base at H. Then $H R_1$ is the initial compression of the spring required, $H R_2$ is the total compression, $R_1 C_1$ and $R_2 C_2$ are the minimum and maximum loads or pressures due to these compressions. Obviously the spring may be such as to give any desired maximum and minimum speed of revolution which will balance it in those positions; or the governor may be made isochronous, if the initial compression bears the same ratio to the total compression that the minimum radius of the balls bears to the maximum.

Screwing up the Springs.—This necessarily increases the mean speed of the governor, since it increases the load to be overcome; but it also increases the sensitiveness. This will be obvious by inspection from Fig. 28, Plate 77, which is constructed like Fig. 27, but with several centripetal lines parallel to each other. These show

the centripetal forces exerted by the same spring with more or less initial compression. If the minimum speed is 57, the maximum is 90, as in the lowest line; but if the speed at the least radius be 125, that at the greatest radius is only 120. For the increase of centripetal force due to the spring is a constant quantity; whilst to maintain the sensitiveness unaltered the difference between the centripetal forces at the extreme positions of the balls should increase with the square of the speed.* If screwed up too much, the governor "hunts," because the speed required to open the balls is greater than that at which they begin to close. The governor balls, when they begin to move, are in unstable equilibrium, and travel rapidly from one extreme to the other. The speed of the engines alternates from the maximum to the minimum, the governor balls pausing at the least radius while the speed rises, and *vice versâ.* These results from screwing up the spring are evidently true, whatever the form

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* Let d = the increase of centripetal force due to the increased compression of the spring, as the governor balls pass from the minimum radius r_1 to the maximum radius r_2.

Let c_1 and c_2 = the centrifugal forces at radii $r_1\, r_2$, and at a speed of one revolution per minute.

,, C_3 and C_4 = the centripetal forces with the spring screwed up, at radii $r_1\, r_2$ respectively.

,, S_3 and S_4 = the corresponding speeds.

Then $$S_3 = \sqrt{\frac{C_3}{c_1}} \quad \ldots \ldots \quad (1)$$

$$S_4 = \sqrt{\frac{C_4}{c_2}} \quad \ldots \ldots \quad (2)$$

Let $\frac{r_2}{r_1} = n$; then $c_2 = nc_1$.

Now $C_4 = C_3 + d$

Hence $$S_4 = \sqrt{\frac{C_3 + d}{n\, c_1}} \quad \ldots \ldots \quad (3)$$

It follows from equations (1) (2) and (3), if the spring be screwed up to give an initial centripetal force = C_3, that S_3 (the speed at the least radius r_1) will be $<$ = or $>$ S_4 (the speed at the greatest radius r_2) according as C_3 is $<$ = or $>$ $\frac{C_3 + d}{n}$. Hence by equation (1) the speed at which the governor will be isochronous in its extreme positions will be $\sqrt{\frac{d}{c_1\,(n-1)}} = \sqrt{\frac{d}{c_2 - c_1}}$

of the centripetal curve may be; and are therefore the same in all known forms of spring governors. To increase or diminish the speed of any spring governor, stiffer or weaker springs must be used, since screwing and unscrewing any particular spring would make it either too sensitive or too sluggish, excepting for very small adjustments. (See Note E, page 428.)

Angle of the Bell-Cranks.—In Fig. 27, Plate 77, the radial distance of the point where the centripetal curve is intersected by the line indicating the mean centrifugal force is the radial distance of the governor balls at mean speed. It appears from inspection that the mean radius of the balls with a rectangular bell-crank must be greater than the radius due to the mean speed.* To correct this the angle of the bell-crank, B C F, Fig. 23, Plate 78, has been increased. This causes the centripetal lines (in such a diagram as Fig. 10, Plate 76,) to become curved. The exact effect of increasing the angle has been calculated for a progressive series of angles and for various mean speeds. This effect is indicated in Figs. 29 and 30, Plate 77, by "variation curves." Thus the vertical from point 5 to the upper curve, Fig. 29, gives the variation of speed, above or below the mean, at 0·5 of the travel, the crank-angle being 90°, and the sensitiveness 2 per cent.; and similarly for the other curves. The angle of crank chosen for the Automatic Expansion Regulator is 96°, but for the governor with 5 per cent. limits of speed the angle may be increased.

Thus in Fig. 23, Plate 78, when the spring E is at right angles to its lever C F, the ball levers C B make an angle greater than 90° (such as 96°) with the direction of the centrifugal force, in order to make the mean position of the governor weight nearly correspond with the mean speed. These considerations apply equally to the governor on the crank-shaft, Figs. 13, 14, and 18 to 21, Plates 78 to 80; and the position of its spring-levers must be determined on the same principles, so as to make the two forms nearly equally sensitive

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* This renders the governor too sluggish when nearly closed, and too sensitive when nearly open—a fault the opposite to that of the ordinary pendulum governor, whose centripetal lines (see Fig. 10, Plate 76) are too much curved.

at corresponding radial positions of the balls. Rollers F F, Fig. 23, Plate 78, carry the pressure of the spring to the end of the levers, and are used in preference to links, because by this means the direction of the pressure is always exactly parallel to the axis, thus maintaining the correct relation of the cosines of the angles which C B and C F make with the vertical and horizontal respectively. The varying inclinations of connecting links were found to produce inadmissible irregularities in the various curves.

The relation between the position of the link-block in its link and the point of cut-off, with the automatic regulator, Fig. 22, Plate 78, is shown in Fig. 31, Plate 77. The link itself is shown on the left. The length of the horizontal base line represents the stroke of the piston; and the horizontal distances of the curved line from O P give the mean points of cut-off for the corresponding heights of the link-block in the link. By means of this curve the points of cut-off may be marked on the link itself, as shown.

The relation between the height of the governor slide D, Fig. 31, Plate 77, and the mean pressure on the piston with 60 lbs. initial pressure (as in Fig. 2) is shown by Fig. 32. The horizontal distances to the curved line represent the mean pressures on the piston in lbs., corresponding to the heights of the governor slide, which are marked in tenths. These mean pressures vary a little according to the proportions of the valves and gear, and of course vary with the initial pressure of steam on the piston. Assume Fig. 32 to be correct for any automatic regulator whose sensitiveness is 4 per cent., with its variation curve like Fig. 30. Then, when the mean position of the governor is at 5 in Fig. 32, the engine would be very nearly at the mean speed, and at the mean pressure on the piston, or 30 lbs. If one-third of the work were thrown off, reducing the mean pressure to 20, the position of the governor slide would be at 6 in Fig. 32, and the speed of the engine would be increased, as shown by Fig. 30, only about $\frac{3}{4}$ per cent. In like manner, if half the load were taken off, reducing the mean pressure to 15 lbs., the position of the governor would be about 6·6 on Fig. 32, showing an increase of speed of only about $1\frac{1}{8}$ per cent. on Fig. 30. Thus it will be noticed that great variations of load are required to produce 1 per cent. variation in speed.

Applications of the governors.—The expansion governor, as already noticed, has been adopted by Messrs. E. R. & F. Turner on all their 8-HP. engines since the Cardiff show of 1872: the first few made were however replaced by the later form which has been described. It has also been much used, acting upon the expansion valve, for various fixed engines made by Messrs. Turner themselves, and also by Messrs. Allen Ransome & Co. and others. The expansion regulator has been extensively used by Messrs. Marshall Sons & Co. on engines of all sizes, fixed and portable, and on all their large stationary engines. It has been applied to large compound condensing engines, and has been comparatively much used for electric-light engines.

Indicator Diagrams.—Those for the expansion governor with single slide-valve are identical with those produced by link motion, as will be seen by those shown in Fig. 33, Plate 81. Fig. 34 shows others taken with a separate expansion-valve; and these are identical in general arrangement with those obtained from the automatic regulator.

NOTES.

Note A. In designing this governor and its valves, the chief points to be arranged are the position and adjustment of the eccentrics. The less the linear adjustment of the eccentric the less the incline of the quadrant, and the more readily will the governor control the eccentric. With condensing engines which do not require a late admission one port will suffice; but with large non-condensing engines, which require steam to be admitted to $\frac{6}{10}$ the stroke, triple ports may be necessary, and the cut-off eccentric should be less than 25° in advance of the eccentric for the main-valve. The main-valve should have lap enough to open the port, say by three-fourths its width, at the end of the stroke, to get suitable compression and avoid back pressure. The valve ports should be as close as is possible without risk of admitting steam at the back edge with an early cut-off. The writer arranges these details without the aid of a model, by

using the valve diagrams 5 and 7, which were published in a letter to *Engineering*, Jan. 1, 1869, Vol. 7, page 14. The governor cannot be too powerful, provided it be not too costly; 5 to 8 ft.-lbs. per I.H.P. has been found sufficient.

Note B. The size of a spiral spring may be calculated from the formula on page 304 of "Rankine's Useful Rules and Tables"; but experience with Salter's springs has shown that the safe limit of stress is more than twice as great as there given, namely 60,000 to 70,000 lbs. per sq. in. of section with $\frac{3}{8}$ in. to $\frac{1}{4}$ in. wire, and about 50,000 with $\frac{1}{2}$ in. wire. Hence the work that can be done by springs of wire is four or five times as great as Rankine allows.

For $\frac{3}{8}$ in. wire and under,

$$\text{Maximum load in lbs.} = \frac{12{,}000 \times (\text{diam. of wire})^3}{\text{Mean radius of springs.}}$$

$$\text{Weight in lbs. to deflect spring 1 in.} = \frac{180{,}000 \times (\text{diam.})^4}{\text{Number of coils} \times (\text{rad.})^3}$$

The work in foot-pounds that can be stored up in a spiral spring would lift it above 50 ft. Thus the weight of the spring in lbs. need not exceed $\frac{1}{30}$ the "governor power" in foot-lbs.

In a few rough experiments made with Salter's springs the coefficient of rigidity was noticed to be 12,600,000 to 13,700,000 with $\frac{1}{4}$ in. wire; 11,000,000 for $\frac{11}{32}$ in.; and 10,600,000 to 10,900,000 for $\frac{3}{8}$ in. wire.

Note C. The resistance to the motion of governor balls, due to the constant work done in overcoming the friction of the throttle valve &c., will be inversely as their travel; for resistance $\times$ travel = work done. The detention due to this resistance at any given minimum speed will be inversely as the centrifugal force, and therefore (page 413 above) inversely as the radius. To give the least radius the maximum advantage (assuming that the maximum radius is fixed) the product of the least radius and the travel must have a maximum value, and therefore the two must be equal. It has sometimes been supposed that because the weights of a gravity governor are constant, while the resistance of a spring is least at

the least radius, therefore the spring governor has a disadvantage. In either case the minimum centrifugal force is balanced and no more, the weight at that time rising more slowly. In each case it is the magnitude of the minimum centrifugal force, and not the mode in which it is balanced, which determines the magnitude of the increase of that force due to an increase of speed.

The two governors described on page 420, Figs. 9 and 25, are numbers 6 and 12 of a series. After many unsuccessful attempts to form a rational basis for this series, these sizes were drawn to embody all the latest experience, and logarithms were taken of all their similar dimensions. From these were formed a series of equidistant logarithms (*i.e.* in arithmetical progression), and from their corresponding numbers the intermediate sizes were drawn.

Note D. It is essential to good governing to have a sufficient fly-wheel. The "rules of thumb" usually found in engineers' pocket-books ignore the laws of dynamics, and are of no assistance.

The writer has used the following approximate formula, derived from Prof. Rankine's "Useful Rules and Tables," rule XI., page 247.

Let D = Diameter of fly-wheel in feet, measured to centre of rim.
N = Number of revolutions per minute.
W = Weight of rim in cwts.
V = Variation of speed per cent. of the mean speed.

$$\text{Then } W = \frac{\text{I. H. P.} \times 65{,}800{,}000}{V \times D^2 \times N^3},$$

$$\text{or } = \frac{A\,P\,S \times 4{,}000}{V \times D^2 \times N^2},$$

where A P S = area of cylinder in sq. in. × mean pressure per sq. in. in lbs. × stroke in feet.

The above formulas are for non-condensing engines, cutting off at $\frac{1}{3}$ to $\frac{1}{4}$ the stroke. For ordinary non-automatic expansion engines the constants in the above formulas may be $\frac{1}{5}$ less.

Small engines are assisted to run steadily by the momentum of the machinery they drive.

The value of V, or the variation permissible in portable engines,

should not exceed 3 per cent. with an ordinary load, and 4 per cent. when heavily loaded. In fixed engines, for ordinary purposes, $V = 2\frac{1}{2}$ to 3 per cent. For good governing or special purposes, such as cotton spinning, the variation should not exceed $1\frac{1}{2}$ to 2 per cent.

NOTE E. The springs for either of these governors may be conveniently calculated as follows, dimensions being in inches.

Let W = weight of the balls or weights.

" r_1 and r_2 = the maximum and minimum radial distances of the centre of the balls, or of the centre of gravity of the weights.

" l_1 and l_2 = the leverages, *i.e.* the perpendicular distances from the centre of the weight-pin (C, Figs. 13, 22, &c.) to a line in the direction of the centrifugal force, drawn through the centre of gravity of the weights or balls at radii r_1 and r_2.

" m_1 m_2 = the corresponding leverages of the springs.

" C_1 and C_2 = the centrifugal forces, for 100 revolutions per minute, at radii r_1 and r_2.

" P_1 and P_2 = the corresponding pressures on the spring.

(It is convenient to calculate these and note them down for reference.)

Let C_3 and C_4 = maximum and minimum centrifugal forces.

" S = mean speed (revolutions per minute).

" S_1 and S_2 = the maximum and minimum number of revolutions per minute.

" P_3 and P_4 = the pressures on the spring at the limiting number of revolutions (S_1 and S_2).

" $P_4 - P_3 = D$ = the difference of the maximum and minimum pressures on the springs.

" V = the percentage of variation from the mean speed, or the sensitiveness.

" t = the travel of the spring.

" u = the initial compression.

" v = the stiffness in lbs. per inch.

" w = the maximum compression = $u + t$.

The mean speed and sensitiveness desired are supposed to be given. Then—

$$S_1 = S - \frac{SV}{100} \qquad S_2 = S + \frac{SV}{100}$$

$$C_1 = 0{\cdot}28 \times r_1 \times W. \qquad C_2 = 0{\cdot}28 \times r_2 \times W.$$

$$P_1 = C_1 \times \frac{l_1}{m_1} \qquad P_2 = C_2 \times \frac{l_2}{m_2}$$

$$P_3 = P_1 \times \left(\frac{S_1}{100}\right)^2 \qquad P_4 = P_2 \times \left(\frac{S_2}{100}\right)^2$$

$$v = \frac{D}{t} \qquad u = \frac{P_3}{v} \qquad w = \frac{P_4}{v}$$

It is usual to give the spring maker the values of P_4 and of v or w. To ensure proper space being provided, the dimensions of the spring should be calculated. The diameter of spring being assumed, the diameter of the wire for load P_4 can be calculated from Note B, first formula, and the number of coils to give V from the second formula; whence the least length of the spring as compressed can be determined.

The governor power $= \frac{P_3 + P_4}{2} \times \frac{t}{12}$. In the case of Fig. 27, Plate 77, with a straight centripetal line, the governor power $= \frac{C_3 + C_4}{2} \times \left(\frac{r_2 - r_1}{12}\right)$. For a preliminary determination of the governor power, it may be taken as equal to this in all cases, although it is evident that with a curved centripetal line, as in Fig. 10, Plate 76, it will be slightly less. The difference D must be constant for the same spring, however great or little its initial compression. Let the spring be screwed up until its minimum pressure is P_5. Then to find the speed

$$P_6 = P_5 + D$$

$$S_5 = 100 \sqrt{\frac{P_5}{P_1}} \qquad S_6 = 100 \sqrt{\frac{P_6}{P_2}}$$

The speed at which the governor would be isochronous would be—

$$100 \sqrt{\frac{D}{P_2 - P_1}}$$

Suppose the pressure on the spring with a speed of 100 revolutions, at the maximum and minimum radii, was 200 lbs. and 100 lbs.

respectively. Then the pressure of the spring to suit a variation from 95 to 105 revolutions will be

$$100 \left(\frac{95}{100}\right)^2 = 90 \cdot 2, \text{ and } 200 \times \left(\frac{105}{100}\right)^2 = 220 \cdot 5.$$

That is, the increase of resistance from the minimum to the maximum radius must be 220 − 90 = 130 lbs.

The extreme speeds due to such a spring, screwed up to different pressures, are shown in the following Table:—

Revolutions per min., balls shut...	80	90	95	100	110	120
Pressure on spring, balls shut .. .. lbs.	64	81	90	100	121	144
Increase of pressure when balls open fully lbs.	130	130	130	130	130	130
Pressure on spring, balls open fully .. lbs.	194	211	220	230	251	274
Revolutions per min., balls open fully	98	102	105	107	112	117
Variation, per cent. of mean speed	10	6	5	3	1	—1

The speed at which the governor would become isochronous is 114.

Any spring will give the right variation at some speed: hence, in experimenting with a governor, the correct spring may be found from any wrong one by a very simple calculation. Thus, if a governor, with a spring whose stiffness is 50 lbs. per inch, acts best when the engine runs at 95, 90 being its proper speed, then—

$$50 \times \left(\frac{90}{95}\right)^2 = 45 \text{ lbs., is the stiffness of spring required.}$$

To determine the speed at which the governor acts best, the springs may be screwed up until it begins to "hunt," and then slackened until the governor is as sensitive as is compatible with steadiness.

Abstract of Discussion on Governing by Expansion Gear.

Mr. Hartnell exhibited an expansion governor placed on the crank-shaft, Figs. 13 and 14, Plate 78, with its valve and cut-off valve, as in Fig. 16, Plate 76, belonging to a fixed engine where there was plenty of room to get an open drum. Also a governor of the form shown in Figs. 18, 19, and 20, Plate 79, with a common slide-valve; this governor was that of an 8-HP. portable engine. Also the form shown in Fig. 21, Plate 80, with a common slide-valve, this being the governor of a Gyppeswick engine. These governors were all lent by Messrs. E. R. and F. Turner of Ipswich. He likewise exhibited an automatic expansion regulator, with its link gear, as shown in Figs. 22, 23, and 24, Plate 78, with its slide-valve and cut-off valve, the latter double-ported at each end; this belonged to an 8-HP. portable engine, and was lent by Messrs. Marshall Sons & Co., of Gainsborough.

Mr. Frederick Turner said the paper just read was so explicit that he was afraid he could add very little. He could only speak from the experience he had had in manufacturing these governors. Within the last ten years his firm had made many hundreds of the form shown in Fig. 18, Plate 79, and they had all worked remarkably well. The saving of fuel in many cases had been about 33 per cent. The work for which these engines were mostly used was very irregular, particularly when driving thrashing machines and saw mills. In such cases the advantages of the governor came out with great force. Very little wear and tear had been discovered, except at one point, where the block bore upon the quadrant. That part had at first been made without adjustment; but afterwards he had added a rather complicated and delicate adjustment—a wedge and screw arrangement—which practically answered well. Since this had been applied, there had been no difficulty at all with regard to the wear of the governor. Every other part was so efficiently supplied with large wearing surfaces, that governors had come home after five years' work in almost as good order as they went out.

Mr. W. H. MAW wished to testify to the admirable manner in which the Expansion Regulator, Fig. 22, Plate 78, worked. He had in his charge six engines fitted with that governor; the largest of them indicated generally about 190 horse-power. He had fitted to that engine a governor, which would have been at work five years next October, and he had had no trouble with it whatever: the engine worked with a very variable load, often having 50 or 60 horse-power thrown off suddenly; but it was impossible to notice any variation of speed. The paper referred to the necessity of having a heavy fly-wheel on an engine fitted with a very sensitive governor; and that was a very important point in securing successful working. The large engine he had just spoken of had a fly-wheel with $6\frac{1}{2}$-ton rim, 10 ft. 6 in. diam., running 112 revolutions a minute. He believed this had had a great deal to do with the success of the governor under very trying circumstances. The smaller engines were indicating from 10 to 30 horse-power. Two of them had been working with the governor nearly as long as the large one, or five years, and he had had no trouble with them. There was no excessive wear in any parts of the governor; he thought no alteration whatever was needed in that direction.

Prof. H. S. HELE SHAW said the importance of the subject of regulating by means of the expansion was admitted by all; and the present paper, though concise, was an extremely suggestive one. It was divided into two portions; he would confine his attention to the first, which was again subdivided into two parts—the advantages of automatic expansion with regard to the economy of steam, and also with regard to the regulation of speed. It might be presumed from the paper that the economy of fuel by means of automatic expansion was taken to be proved by the diagrams, Figs. 1–3, Plate 74; but he thought it a pity that more data had not been given about those diagrams, as they would add much to the value of the paper. Thus in Fig. 4 the ordinates were said to represent lbs. of water per HP. per hour. The arguments in the paper were, up to this point, based upon the quantity of steam used. Now although there might be some direct proportion between the steam

and the feed-water, yet if those results had been obtained by merely measuring the feed-water, most engineers would think their value very much lessened. With regard to the regulation of speed, he should like to suggest, instead of the terms retardation from storage and retardation from friction, the terms retardation *due to* storage and retardation *due to* friction. The diagrams in connection with the second part of the paper, Figs. 7 to 12, Plates 75 and 76, were apparently hypothetical, and drawn without reference to any particular data. Yet of course some conditions must have been assumed for the purpose; and the results would vary considerably as the data varied. Indeed it was said on p. 416, "It is however but just to state that the same effect could be produced with the throttle-valve, if friction were a very small fraction of the governor power, and if storage could be got rid of." He pointed this out because it seemed at variance with the sentence immediately preceding, "By comparing Fig. 7 with Fig. 12, the immense advantage of governing the cut-off gear will be apparent." In these matters the author's reputation was so great that it would be very valuable if he would give more explicit data with regard to his various statements.

There was only a meagre allusion to the part the fly-wheel played in regulating motion, especially in large engines. The object of automatic expansion was to maintain as nearly as possible a uniform speed, with the least expenditure of power in governing. In large engines of course the fly-wheel formed part of a very efficient automatic apparatus. Small engines, especially of the class that had recently become so important in connection with electric lighting, could not have a large fly-wheel; and here recourse must therefore be had to some automatic gear, in order to obtain as nearly as possible regularity of speed. But absolute regularity could never be obtained, as long as the present lines were followed. Some change in the speed of the engine had to take place before any of the governors now in use would come into operation. He had for some time thought that some means of storing the power of the engine ought to be sought; and with engines generating electricity a possible solution of the problem might occur to some of those present. The action must be such that with a decrease in the load a storage of energy

might take place, and with an increase in the load that store might be drawn from, while the automatic apparatus was coming into operation.

Mr. Druitt Halpin thought the paper was an admirable one, and he quite believed in the author's system, which was at one of the extremes in regard to governors. There were some governors that did nothing but indicate what ought to be done; while the author's governor acted by what might be called brute force. He had seen engines working with these governors in many parts of the country with the greatest regularity, and had tested them himself. The only part of the paper with which he could not agree was p. 411, where it was said that the governor had merely to hold the gear still, or else permit it to move itself. He had once been under the same idea, that a governor would be artful enough to work just when the engine was doing nothing; that when the piston was at the end of the stroke, and there was no motion, the governor would watch the chance and move the slide-block to produce the requisite change: but he had got into trouble by not having a sufficiently powerful governor to move the automatic gear.

Mr. M. Powis Bale asked whether there had been any trouble with the springs in the governor? In the business with which he was connected—wood-working machinery—constant and severe changes of loads were found in time to have a bad effect upon the springs. In several band-sawing and trying-up machines, in which spiral springs were employed, he had found, after some years of work, that the springs, from the constant and severe shocks, lost their elasticity to a certain degree. If that were the case with the springs in the governors, of course the sensitiveness of the governors would be impaired. He also wished to ask whether it had been found that temperature had any effect on the springs. As he had had several breakages with spiral springs, he now used flat or coach springs instead, which had been found to stand well.

Mr. Arthur Paget said, with regard to the question of such reciprocating springs, it might be useful as a matter of information

to state that, though something depended on the quality of steel, much more depended on the amount of stress to which they were exposed. He had used in 1860 a number of springs of ordinary quality for some machines in which the reciprocations of the springs were at the rate of 100 to 120 per minute. For fifteen years those springs had been running ten hours a day, and since then nine hours a day, and they appeared to be now as good as when they were first made. Therefore if the springs in the governor were, as they appeared to be, well proportioned to their work, there should be no danger that they would wear out or sensibly deteriorate in any reasonable number of years.

Mr. T. R. Crampton said there could be no doubt that the question brought before the Institution by Mr. Hartnell was a very important one; but he thought so extended a range of variation was not always desirable as appeared on the diagrams, Figs. 33 and 34, Plate 81. Taking the set in Fig. 34, for example, the upper pair, with the latest cut-off, were perhaps as good diagrams as could be obtained. These, it appeared, were from an engine worked with a separate expansion-valve. Looking at the exhaust end of the diagram, the steam appeared to be expanded nearly down to the friction point, which in non-condensing engines was about 6 lbs. above the atmosphere; and nothing was gained by expanding below that. But suppose the cut-off to be as early as shown in the lower pair: then the atmospheric line was reached some distance from the end, and the friction due to the engine for the remaining distance had to be deducted from the useful effect, resulting in a considerable loss.

Then there was another question, namely with regard to wire-drawing. The diagrams in Fig. 33, Plate 81, appeared to be from an engine worked by an ordinary lap-valve. The theoretical diagram would give results a little better than those diagrams, where the port closing gradually produced a rounding of the line. But in some cases the loss thus occasioned was hardly worth considering, particularly if separate valves had to be employed to avoid it. He himself preferred, where single lap-valves were employed, so to arrange the throttle-valve, or the regulating valve worked by the

governor, as that the steam did not expand through the valve-chest, but only through the port itself. With this mode of wire-drawing, a good result was obtained by very simple means.

Mr. Hartnell said there was no throttle-valve with any of these diagrams.

Mr. Crampton said it was at any rate apparent by the diagram that the cut-off had been such that there was a certain amount of wire-drawing or throttling by the gradual closing of the passage. Taking the loss thus occasioned, as compared with a perfectly sharp cut-off, he maintained that it was an insignificant percentage of the total steam, and not worth consideration; yet he had known great expense incurred to reduce it. It was often remarked that this or that diagram was not a sharp one, that this diagram was not as beautiful as that, because of the little rounding at the angle, &c. He hoped the young members of the Institution would not regard that rounding as very objectionable, or try to get a sharp angle, if the latter involved any complication. As good a practical diagram could be produced with one valve on the top of the other, and worked by eccentrics, as with any valve that was ever made. He could show diagrams produced thirty years since with such valves, expanding from 12 grades down to $1\frac{3}{4}$, proving this. Many years since he had been very much occupied with the subject of wire-drawing steam, and if they would look at some old patents of his, they would find he purposely used wire-drawing. But he did not wire-draw through the valve-chest, but from the port itself, the steam at first going direct into the cylinder at boiler pressure and then diminishing in pressure as the piston got away from it, which produced the best wire-drawing or semi-expansion. But it should only be adopted where considerable expansion was required, with the use of the ordinary lap-valve cutting-off at say one-third of the stroke, and wire-drawing before that point: then it would give better commercial results than a more theoretically correct diagram produced by the complication of separate valves.

Mr. Hartnell in reply said he was sorry that neither Mr. Crompton nor Dr. Siemens was present, nor others who had used the machine for electric lighting, because that was where regularity was essential. With regard to the fly-wheel, it was obvious that, unless its rim were so heavy that the variations of speed in every semi-revolution were less than the variations of speed due to the governor, the unsteadiness of the fly-wheel would tend to make the governor balls vibrate to their extreme positions at each stroke of the piston, so that the governor could not regulate the engine within those limits of variation. The governor put up by Mr. Maw, the first large one of the kind, was for the *Daily Telegraph* printing office. The speed was required to be very steady under great variations of load; and on his stipulating that the fly-wheel should not allow a greater variation of speed than 2 per cent. during each revolution, Mr. Maw had replied that it would not allow 1 per cent. He then calculated the springs, and made a special angle for the governor, for a variation under 3 per cent.; and it was afterwards proved by experiment that 60 or 70 HP. could be taken off the engine with less than 1 per cent. variation in speed; Mr. Maw had stated that the whole power could even be thrown off the engine with very little variation of speed. In those large printing offices, the machines had to run as fast as they could with safety, and the engine must not go any faster when the work was taken off.

In regard to the point raised by Mr. Halpin, that the governor had nothing to do but merely to allow the valve to move, that was certainly not strictly true. It should have been said that the governor had comparatively little to overcome beyond the friction of its own mechanism: that the force required to move the eccentric against the action of the valve was derived from the resistance of the valve to the revolution of the eccentric, as shown by Fig. 15, Plate 77. If the governor was powerful enough to hold the gear, it would move itself; but as there was a certain amount of friction, and as there were only small variations of speed to produce the governing power, he had in every case made the governor as powerful as possible, so that the governor could readily "use its opportunities" when the valve was at the end of its stroke (and therefore passive),

and could assist when the resistance of the valve acted with the governor.

The strain put upon the springs was twice what Rankine had given in his Tables. The springs themselves had always been satisfactory. There had not been an instance of their growing weak. He believed Mr. Maw had used them for five years, but he had never heard of one breaking.

With reference to the point raised by Mr. Crampton as to the uselessness of expanding too far, he so thoroughly agreed with him that he need not say anything more upon the subject. In the case of Messrs. Turner's engines, made for the Cardiff show, it had been necessary, in order to meet the conditions of the Royal Agricultural Society, to choose such a load that the engines should be able to run the longest possible time against the friction brake. To meet those conditions the steam was expanded to such an extent only as to ensure that its terminal pressure should be always above the measured average frictional resistance of engine and brake combined. In the case of the engines designed for Messrs. Marshall, in order to ensure the correct degree of expansion, a table was printed giving the size of the engines and the best "commercial load" for each, with both 60 lbs. and 80 lbs. boiler pressure. This load was calculated for a terminal pressure about 10 lbs. above the atmosphere. When engines were thus loaded, automatic expansion governors did not expand too much. The lower indicator diagram in Fig. 34, Plate 81, showed expansion further than was desirable for an ordinary average load. The compression was a weak point in governing with simply an ordinary slide-valve, as in the diagrams in Fig. 33. It was found by experiments with the friction brake, governing with a single valve only, that with a light load the indicated power increased as the pressure increased, because of the increased frictional resistance due to the increased compression. If engines were wanted to run lightly, they should not have too much compression or lead. In the case of larger engines, it would be better to use the double valve, with either of the governors.

The PRESIDENT asked what the effect would be if a spring were to break in the governor.

Mr. Hartnell replied that the governor would shut the steam off at once, the weights flying out to the furthest position. With regard to the diagrams as to retardation from friction &c., they were merely meant to illustrate the conclusions drawn; because anyone who knew the subject could see that an elaborate paper might be written on each of those headings. So far as he was aware, no matter had been printed in reference to those points, and the greatest confusion of thought existed in many minds as to the reason why an engine sometimes started to race with but a slight variation of load. Anyone who had studied the subject would know what he referred to; and even stating the matter approximately, as he had done, required a great deal of thought.

ON AN AUTOMATIC HYDRAULIC SYSTEM FOR EXCAVATING THE CHANNEL TUNNEL.

[Lecture delivered by THOS. R. CRAMPTON, Esq., Member of Council, at the Conversazione at Leeds, 16th August, 1882, and published by order of the Council.]

The question of constructing tunnels of considerable length has of late been brought more prominently into public notice by the successful completion of the tunnels through the Mont Cenis and the St. Gothard. In both cases the nature of the rock through which the tunnel had to be cut was such that the rate of advance was comparatively slow, and the quantity of *débris* which had to be removed daily was inconsiderable; consequently the traffic by trucks or wagons, which the removal of such *débris* necessitated, offered no serious difficulties, and did not to any great extent interfere with the operation of lining such portions of the tunnel as had already been excavated.

But when the material through which the tunnel has to be cut is of so soft a nature that blasting operations can be dispensed with, and ordinary appliances, such as boring or cutting tools, can be employed, then the rate of advance may become practically unlimited —being, in fact, controlled mainly by the greater or lesser facility with which the *débris* from the face can be removed from the tunnel.

So far as I am aware, there is not now in practical use any other mode of dealing with the *débris* of tunnel perforation, than that of transport by means of trucks and wagons running on rails, as employed in coal mines. The system of removal which I propose to use, and which will be more particularly treated in this lecture, is applicable only in the case of tunnels through chalk or similar materials; and for the purpose of illustration, I may be allowed to connect it for the moment with one of the most prominent engineering problems of the day, namely the proposed submarine tunnel between England and France.

This is supposed to pass for its whole length through a uniform stratum of grey chalk without water. I eliminate therefore all questions of meeting with hard rock, or with any large quantities of water during construction. Such questions will have to be dealt with in any case as they arise, and by ordinary means.

The tunnel is assumed to be 20 miles long, independent of approaches on either side; to be excavated 36 feet in diameter in one operation, which, with an internal lining of 3 feet all round, will leave a clear tunnel 30 feet in diameter; and the work to be commenced simultaneously at both ends. It follows therefore, since the approaches may be made at the same time as the main tunnel, that we need only consider here a length of 10 miles of excavation worked from one face.

Practical trials made with machines in chalk many years since, established the fact that a rate of advance may be easily maintained of one yard per hour, or 24 yards per day; at which rate the work of excavating 10 miles of tunnel would take $2\frac{1}{2}$ years to accomplish, taking the year at 300 working days. With the simple apparatus now exhibited, 12 in. in diameter, as much as 5 yards forward per hour has been cut. The advance of one yard forward per hour in a 36-foot tunnel will necessitate the removal of 113 cubic yards of chalk per hour. In order to ensure the due performance of the necessary work, I will add 50 per cent. to the figures here given, and shall henceforth deal with other items in the same proportion. We have to provide then for the removal of 170 cubic yards of *débris* per hour, equal in weight to 250 tons—a greater quantity than is lifted in two of our greatest collieries together, in the same time.

If we now assume the use of the ordinary system of removal by trucks, we find that the transport of 170 cubic yards of *débris* per hour would require the passage of 85 trucks of two cubic yards each per hour, or one truck every 42 seconds: thus, if trains are made up of ten wagons each, there will be one such train every seven minutes passing out, and a similar train of empties coming back continuously. Of course heavier or lighter trains may be used as thought most desirable.

Arrangements must then be made for raising these wagons to the surface up the vertical shaft, 450 feet in height; and this means the lifting of 255 tons per hour, or 6000 tons per 24 hours, independent of the weight of wagons, men, tools, stores, &c. The wagons may of course be drawn up inclined approaches, but I assume they will be lifted.

The lining of the tunnel three feet all round requires materials to the amount of 34 cubic yards per hour, or, with 50 per cent. added for contingencies, 50 cubic yards per hour. These materials will, of course, be introduced by the empties going back to the working face of the tunnel, and will be discharged where required at different parts of the tunnel.

It will be easy, without entering further into details, to understand the difficulties to be overcome in accomplishing a task of such magnitude as the lining of the tunnel, at a rate keeping pace with the advance of the boring machinery, while so great a traffic of *débris*, &c., in trucks is going on in both directions almost uninterruptedly.

The system by the use of which I would propose to obviate some of these difficulties eliminates four-fifths of this movement in trucks. It is founded upon the employment of hydraulic power for driving all the machinery required to cut down the chalk at the tunnel-face, and to remove the *débris* out of the tunnel to the surface, or to any place where it can be disposed of.

For the moment the question of different levels in the tunnel will be disregarded, and I will treat the question on the assumption that the whole length of 10 miles is executed on a level 400 feet below the level of the sea; and further, that the arrangements are such as if the work of excavation and the removal of the *débris* had all to be carried on at a distance of 10 miles from the starting point.

Near the mouth of the upright shaft, A, Fig. 1, Plate 82, powerful machinery will be erected to pump water from the sea, to compress it, and to hold it under pressure, by means of force pumps and accumulators. The water will be compressed at the top to 512 lbs. per sq. in., and the fall through 400 feet from the sea-level will add another 188 lbs. per sq. in.—producing thus at the bottom of the shaft 700 lbs. per sq. in., a pressure commonly employed.

The inlet pipe B, which conducts the water under high pressure down the shaft and to the face, will be lengthened as required by the advance of the boring machinery; and this operation will be facilitated by the interposition between the end of the inlet pipe and the boring machinery of an ordinary telescopic joint C, with a free run of say 72 feet, or 24 yards, whereby only one stoppage will become necessary in 24 hours.

The cutting machinery at the face, Figs. 2–5, Plates 83 and 84, will be driven by an ordinary hydraulic motor D, direct and without the intervention of gearing. The *débris* of the chalk cut down will be taken up by a series of cups, and thrown into a shoot E, to the top of which the waste water from the hydraulic motors is conducted. The water flowing down carries with it the chalk *débris*, and both pass into an ordinary cylindrical revolving drum F, where it is reduced to sludge. The quantity of water used by the hydraulic motors will be so calculated that it will amount to about three times the quantity of chalk *débris* by weight. When mixed with the water in the revolving drum, the very fine *débris* almost instantly dissolves, and the result is a cream or sludge, which, passing through small apertures on the face of the drum, is taken up by ordinary pumps G, worked by hydraulic motors H, and forced through the main outlet pipe J, Fig. 1, to the bottom of the shaft A, or direct up the shaft to the sea if required. The pumps G are placed upon the main frame of the boring machine, and the motors H are driven by high-pressure water, taken from the main inlet pipe B. The main outlet pipe J is provided with a telescopic joint similar to the one described for the main inlet pipe. These two telescopic lengths, being attached to one another, are moved forward together. Between the telescope and main pipe two valves UV are placed, one on the telescope, the other on the main pipe. When the ram is run out, these valves are closed, and the joint I between the valves broken; the telescope is then moved forwards on the ram by opening a small cock K, connecting the ram with a vacuum chamber. The water in the ram will then flow into the vacuum chamber, and the telescope will be drawn over the ram close up to the machine by the air-pressure behind it. The space thus left between the valves UV is filled up by an extra length of pipe, with a valve attached: the small

cock K is shut, the valves U and V opened, and the working resumed. When the machine is required to be brought back, *e.g.* to change the cutters, the rack and pinion will be thrown out of gear, and an ordinary hydraulic ram (not shown) will be used for the purpose.

The cream is forced by the pumps through the excavated portion of the tunnel to the bottom of the shaft, and thence may be raised by pumps or other suitable means to the top, and discharged into the sea, or disposed of in other ways.

It will now be perceived that the space lying between the boring machinery and the shaft is left entirely free, excepting the small portion of it occupied by the two pipes—the pressure-water inlet pipe and the cream outlet pipe. The operation of lining the tunnel may therefore be carried on with the greatest facility, there being no traffic upon the rails, and no hoisting up or lowering in the shaft, except that necessary to transport the workmen and the building materials for lining the tunnel, amounting to only one-fifth of that required on the ordinary system: in other words four-fifths of the whole weight to be disposed of is carried through pipes, instead of by locomotives and trucks.

A few details regarding the power required for the various operations, the size of inlet and outlet pipes, and other data in connection with the hydraulic machinery, may be interesting.

Cutting the Chalk.—A Cutting Machine of the most simple construction will be used, for the purpose of excavating the chalk. As shown in Figs. 2–6, Plates 83 and 84, designed for an 8-ft. heading, it consists of a number of small discs L, placed at an angle, and attached to a large boring head M, made to revolve at any given speed. Each cutting disc removes at each revolution a concentric ring from the face of the chalk, of $\frac{1}{16}$ in. or any other required thickness, and of a width equal to one-fourth of the diameter of the disc; and the discs are arranged to follow each other in such a manner that while they are all continuously in action, yet none has ever more to remove than its apportioned width and thickness of cut. The disc-spindles, Fig. 6, Plate 84, turn freely in their sockets, and as the discs cut only a width about one-quarter of their diameter,

they turn in an opposite direction to that in which the large disc or head M revolves, and act by rolling into the chalk. The cutting edge is thus changed continually, whereby the wear and tear of the edges is reduced to a minimum; and at the same time they do not require sharpening, a most material feature. I have cut with a similar machine at the rate of 5 yards forward per hour, without injury to the cutters. By trials I have ascertained that 2 HP. per cubic yard of chalk excavated per hour would be more than ample power; hence if, in piercing a tunnel 36 feet in diameter, 170 cubic yards of chalk per hour have to be cut down, 340 HP. will be necessary for this part of the work.

The pressure of the incoming water upon the area of the telescopic joint on the one hand, and the back pressure of the cream, forced towards the exit, on the other, will always push the machine forward automatically; and it becomes necessary to provide an arrangement to control this speed, and allow the machine to advance only at the desired speed. There are various simple means of effecting this object: that shown is by screw gear and pinion, working into a rack.

To cut a clear face 36 feet in diameter will require 72 12-inch cutting discs fixed upon the arms or cross-beams, each cutter in one revolution of the machine taking off a concentric ring 3 inches in width, and $\frac{1}{16}$ of an inch thick. Supposing the head M to turn at the rate of 10 revolutions per minute, this would give the outside cutter a periphery speed of 1130 feet per minute, which has been found to be well within practical limits. It will be understood that the cutters turn at different speeds, those near the outer periphery doing considerably more work than those near the centre. With chalk the revolving cutters are found to be equally effective at all speeds.

The sleepers on which the machine slides or runs, and the rack by which its advance is regulated, are made in pieces of convenient length; and as the last piece of the set is left behind, it is continually shifted forward and put down in front. This is effected (see the cross-section, Fig. 5, Plate 84) by means of two arms N N, Figs. 3 and 5, mounted in a line with the main shaft in rear of the machine. These arms are lowered, and bolted to the cross-sleeper P, which has attached

2 N 2

to it lengths of the rails R and rack S. By means of a small hydraulic engine or other means the arms with the sleeper are made to revolve and lifted into the higher position, where they deposit the sleeper &c. on two small carriages T T, running on rollers upon girders Z. These carriages have hooked brackets, as shown, on which the pieces of rail are caught and rest. The arms are then unbolted, and the carriages, with the sleeper &c. upon them, are pushed by hand, or run by gravitation, along the girders Z to the front of the machine, where the sleeper &c. is picked up by exactly similar arms or levers, and brought down and deposited in its place at the bottom of the heading. The girders, with the carriages upon them, can be traversed endways through a short distance, so as to be out of the way while the sleeper is being raised or lowered.

Reduction of the Chalk débris to Sludge or Cream.—Some years since it became necessary for me to design an apparatus which in a small compass could produce large quantities of chalk-cream, such as is used in all cement works.

The apparatus, which has been long in operation, is a plain cylindrical drum, 4 feet in diameter, and 2 feet 8 inches long inside, revolving at the rate of 32 revolutions per minute. One face of this drum is made of a strong wire grating, except in the centre, where a hole of 15 inches diameter is left. Through this central aperture the chalk *débris* and the water, in whatever quantities may be required, are introduced, and as the drum revolves, the particles of chalk, saturated and softened by contact with the water, are quickly dissolved; a cream or sludge, of more or less consistency, is thus produced, which escapes through the meshes of the wire grating and collects in a reservoir. It is then taken up by a pump, and forced to any place required.

In this small apparatus a quantity of chalk *débris*, amounting to 14 cubic yards, or 21 tons, was reduced to cream within one hour.

Fig. 2, Plate 83, shows a drum of the dimensions first given, placed in an 8-foot tunnel, a space considerably larger than is necessary to contain it. It will be a simple question of proportion to determine the size of the cylindrical drums capable of reducing

the 170 cubic yards of chalk *débris* per hour, resulting from the cutting of a tunnel 36 feet in diameter. As a matter of fact, two drums 7 feet diameter and 7 feet in length will be amply sufficient for that purpose.

It will be quite safe to assume, as my experiments show, that one half of a horse-power per cubic yard of chalk per hour is sufficient for its reduction ; this gives a total under this head of 85 HP.

Conveyance of Cream back to the bottom of the Shaft.—Before deciding upon the quantity of water necessary to be mixed with the chalk, for its speedy reduction to cream, I made a series of trials in small pipes, with a view of ascertaining the amount of extra friction which may be caused by the passage of cream through them, as against the passage of water alone. I need not enter into details, but may state at once that while an admixture by weight of equal quantities of chalk and water required nearly 14 per cent. more power than pure water, an admixture of 1 of chalk and 2 of water required $3\frac{3}{4}$ per cent., and an admixture of 1 of chalk to 3 of water only $2\frac{1}{3}$ per cent. ; it was therefore decided to use the proportion of 1 of chalk to 3 of water by weight, or 1 of chalk to 6 of water by bulk. It was also ascertained that it would not be safe to pass cream through long lengths of pipes at a less velocity than 1 ft. 6 in. per second, as otherwise there would be a tendency for the solid particles to settle ; I therefore decided upon a minimum velocity of 2 feet per second, at which to pass the cream.

It was previously stated that 170 cubic yards of chalk *débris* would be produced per yard forward in driving a 36-foot tunnel ; we require therefore $170 \times 6 = 1020$ cubic yards of water per hour, or 17 cubic yards per minute, equal to 459 cubic feet. Now a 12-inch main will deliver this quantity, at the end of 10 miles of pipe, at a pressure of 700 lbs. per square inch ; the water passing through it at a velocity of 9·5 feet per second. The total horse-power developed by this quantity of water, at 700 lbs. pressure, amounts to 1377 HP., at our disposal at the face ; 337 HP. being given by the pressure of the sea, and 1040 by pumping machinery.

The sludge is composed of—

Chalk, 76 cubic feet per minute,
Water, 459 cubic feet per minute,
Total of cream, 535 cubic feet per minute.

The weight of the cream is 72 lbs. per cubic foot.

A main outlet pipe, 20 inches in diameter, will be required to convey the cream back to the bottom of the shaft through 10 miles of level tunnel, the cream flowing through it at a velocity of 245 feet per minute or 4 feet per second. The total head required to force the cream along a level to the bottom of the shaft is 214 feet or $21\frac{1}{2}$ feet per mile. This represents a force of 224 HP., the pressure in the pipe being 96 lbs. per square inch.

Lifting the Cream from the bottom of the Shaft to the Surface.—535 cubic feet of cream, at 72 lbs. per cubic foot, lifted 400 feet per minute, will consume about 525 HP., including contingencies.

Hence the power required for the several operations is as follows:—

(1) Cutting the chalk (page 445)	=	340 HP.
(2) Reduction of chalk to cream (page 447)	=	85 „
(3) Conveyance of cream to bottom of shaft through 10 miles of pipe	=	224 „
Total required at the face	..	649 HP.

As we have provided 1377 HP., there will be no deficiency even if the hydraulic motor should only yield 50 per cent. duty, which is a very low estimate.

The 525 HP., above shown as required for lifting the cream from bottom of shaft to top, will, of course, have to be provided at the top of the shaft, and will be in addition to the power necessary for the compression of the water.

To compress 459 cubic feet of water per minute to a pressure of 512 lbs. per sq. in. would require a force of 1,040 HP. (the sea pressure giving 337 HP. additional).

We have therefore to provide on top of shaft,

For compression of water	. . .	1,040 HP.
,, pumping up the cream	. .	525 ,,
Total	. .	1,565 HP.,

to carry out the entire operation of cutting 170 cubic yards per hour, reducing it to cream, pumping it through 10 miles of pipes on a level into a sump at the bottom of the shaft, and lifting it to the top.

It may be remarked that the cream can be pumped from the face along the tunnel up the shaft in one operation, but more power would be required to do this.

The above power is independent of that required to transport the material necessary for lining the tunnel, which will be done by locomotive or other means, as in the ordinary system.

As an alternative scheme to the one just explained, I would propose, where the tunnel has sufficient fall for drainage, which the Channel Tunnel should have, to do away with the compression of the water on the surface and utilise the pressure of the sea alone; in other words to syphon the water out of the sea and convey it by its own fall 400 feet below the level of the sea, giving a pressure of 188 lbs. per square inch.

In this case the quantity of water, in order to do the work efficiently, must be considerably larger; and instead of a 12-inch main inlet pipe, one of 22 inches will be necessary. If the tunnel is made at an inclination of 1 in 1,000, the cream will flow by gravity to the bottom of the shaft, from which it will be pumped to the top. The larger quantity of water sent down will make the proportion of chalk to water as 1 to 13; in that proportion the cream will run as easily as water itself, and an open drain will be sufficient, dispensing with the closed pipe.

The power required for cutting down the chalk and for reducing it to cream would be the same as in the former case, namely 425 HP.; but the third item of power for forcing the cream to the bottom of the shaft will not need to be provided for. The 22-inch main inlet pipe, under a pressure of 188 lbs. per sq. in., will deliver

974 cub. ft. of water per minute to the face 10 miles off, at a velocity of 368 feet per minute or 6·1 feet per second; representing a total of 800 HP. available, or nearly double that required.

It will be necessary in this case to lift a larger quantity of cream up the shaft—nearly double of what it is in the other case; and the power for this amounts to 950 HP.

We have therefore to provide on top of shaft,

For compression of water . . .	*Nil.*
„ pumping up the cream . . .	950 HP.
Total	950 HP.

as against 1,565 HP. to be provided for in the high-pressure system.

I have shown, I think, that the system I propose to use offers some considerable advantages as regards the traffic in and out of the tunnel, and the consequent facilities afforded for the speedy lining of the tunnel; hence it cannot but result in a great saving in time and expense.

For the few men employed at the boring machinery, I propose to carry sufficient air under compression with the water; which being discharged at the motors will keep that part of the tunnel cool and well ventilated.

For the transport of the comparatively small amount of material for lining the tunnel (about one-fifth of the whole quantity to be moved), electric or air locomotives may be employed. If the latter, the air discharged would ventilate the tunnel; but in either case a very small pipe would convey sufficient air for that purpose.

It may be observed in conclusion, that I consider the power required by the hydraulic system will not amount to one-third of that required when the chalk is cut in a dry state by compressed-air machinery, and has to be conveyed by air-locomotives in trucks, and lifted to the surface by the ordinary means.

EXCURSIONS, ETC.

The afternoons of Tuesday, 15th August, and Wednesday, 16th August, were devoted to visiting various Works in the town and neighbourhood of Leeds, which had been kindly thrown open to the Members: a large number of brakes being in readiness on both days (supplied free by the Local Committee) to facilitate visits to outlying places. A list of the works so thrown open will be found below, p. 454. It is followed by short notices of most of the more important works, which are derived from information kindly supplied from the works themselves, and supplemented in some instances from a series of articles published in *The Engineer* during the months of July and August.

On Wednesday evening the Members and their friends were invited by the Local Committee to a Conversazione at the Philosophical Hall, which was very largely attended. The chair was taken in the lecture room at 8.30, by Mr. James Kitson, Jun., Chairman of the Executive Committee, and lectures were given in the course of the evening as follows:—

Description of some of the Machinery and Models exhibited; by Mr. Henry Davey, M. Inst. M.E.

On the Dynamo-Electric Machine and Electric Transmission of Power; by Professor Rücker, Yorkshire College of Science.

On an Automatic Hydraulic system for Excavating the Channel Tunnel; by Mr. Thomas R. Crampton, Member of Council. (See above, p. 440.)

On Flameless Combustion and Fuel Utilisation; by Mr. Thomas Fletcher, F.C.S.

A selection of music was performed during the evening in the Zoological Room.

Amongst a large number of objects of interest, specially brought together for the occasion, may be mentioned Brush arc lamps, and Lane-Fox incandescent lamps, supplied by the Yorkshire Brush Electric Light and Power Company, and worked by a dynamo machine driven by Messrs. John Fowler and Co.'s Yorkshire

compound engine; De Laval's centrifugal cream separator, contributed by Messrs. D. Hald and Co., and driven at 6000 revolutions per minute through a dynamo machine by a Parsons high-speed engine lent by Messrs. Kitson and Co.; the original model of Blenkinsop's locomotive, contributed by Mr. Embleton (see Mr. Meysey-Thompson's paper, *ante*, p. 268); model of 5500 H.P. unarmoured cruiser, contributed by the President; model of the proposed bridge over the Forth, contributed by Messrs. Fowler and Baker; models of hydraulic coal hoist, and of train-boats as used upon the Aire and Calder navigation, contributed by Mr. W. H. Bartholomew, M. Inst. C.E. (see President's address, *ante*, p. 263); observatory hive, with bees working under the electric light, contributed by Mr. William Daniel, M. Inst. M.E.; diagram of Joule's apparatus for determining the mechanical equivalent of heat, contributed by Mr. Henry Davey, M. Inst. M.E.; and examples of high-speed multiple drilling of long small holes, contributed by Mr. T. R. Harding.

On Thursday afternoon, 17th August, an Excursion was made to Bradford, by special train, provided free by the kindness of the Midland Railway Company. At Bradford the Exhibition of Textile Industries, opened by H.R.H. the Prince of Wales on 23rd June, was visited: here among many objects of interest were seen several textile machines of various kinds in actual operation, including the Wool-Combing machine described by Mr. F. M. T. Lange in this volume (*ante*, p. 214). A visit was also paid to the engineering works of Messrs. Thwaites Bros., and to the mechanical departments of the Whetley Mills (Messrs. Daniel Illingworth and Sons), and the Manningham Silk Mills (Messrs. Lister and Co.). Notices of these works will be found below, p. 466–7.

In the evening the Annual Summer Dinner of the Institution was held in the Victoria Hall, the President in the chair; the number dining was over two hundred.

On Tuesday, Wednesday and Thursday, at the conclusion of the General Meeting, the members were entertained at luncheon in the Victoria Hall, by invitation of the Local Committee.

In the afternoons of the same days there was an exhibition of Ploughing and Cultivation by Steam, arranged by the kindness of Messrs. John Fowler and Co.

Friday, 18th August, was occupied in an Excursion to Hull, which was attended by over 250 members. They travelled by special train, provided free by the kindness of the North Eastern Railway Company, and were set down close to the works of the new Alexandra Dock of the Hull and Barnsley Railway Company. After partaking of refreshments, kindly provided by the contractors, Messrs. Lucas and Aird, they inspected the whole of the dock works, including the hydraulic engine-house and accumulator, already at work, and a "hydraulic navvy," or excavator worked by water-power, which had just been started. They then visited the extensive works of Earle's Shipbuilding and Engineering Company, and from thence were conveyed in carriages, provided free by the kindness of the Hull Reception Committee, to the Assembly Rooms. Here they were entertained at luncheon by invitation of the Reception Committee, the Mayor of Hull occupying the chair. In the afternoon a visit was paid to the West Docks, in a steamer provided by the kindness of the Hull Dock Company; here the works of the new extension were examined, and also the pumping station of the Hull Hydraulic Power Company. Many of the members also visited other objects of interest in the town, which were kindly thrown open. A list of these will be found below, p. 468, together with notices of the works specially visited. The members returned to Leeds in the evening by special train.

WORKS AT LEEDS.

LIST OF WORKS THROWN OPEN TO THE INSTITUTION.

Joshua Buckton & Co., Well House Foundry, Meadow Road.
Fairbairn Kennedy & Naylor, Wellington Foundry, Wellington Street.
John Fowler & Co., Steam Plough and Locomotive Works, Hunslet.
Thomas Green & Son, Smithfield Iron Works, North Street.
Greenwood & Batley, Albion Engineering Works, Armley Road.
Hathorn Davey & Co., Sun Foundry, Dewsbury Road.
Hunslet Engine Co., Jack Lane, Hunslet.
Kitson & Co., Airedale Foundry, Hunslet Road.
Samuel Lawson & Sons, Hope Foundry, Mabgate.
Maclea & March, Union Foundry, Dewsbury Road.
Manning Wardle & Co., Boyne Engine Works, Jack Lane, Hunslet.
Pollock & Pollock, Longclose Engineering Works, Newtown.
Scriven & Co., Leeds Old Foundry, Marsh Lane.
Shepherd Hill & Co., Union Foundry, Hunslet Road.
Smith Beacock & Tannett, Victoria Foundry, Water Lane.
Tannett Walker & Co., Goodman Street Engineering Works, Hunslet.
Joseph Whitham & Son, Perseverance Iron Works, Kirkstall Road.
S. T. Cooper & Co., Leeds Iron Works, Hunslet.
Farnley Iron Co., Farnley.
Kirkstall Forge Co., Kirkstall.
Monkbridge Iron Co., Whitehall Road, Leeds.
Taylor Brothers & Co., Clarence Iron Works, Clarence Street, Leeds.
Hargreaves & Nusseys, Woollen Manufactory, Farnley.
Marshall & Co., Flax Spinning Mills, Marshall Street, Leeds.
John Barran & Sons, Wholesale Clothing Manufactory, Park Square, Leeds.
J. J. Flitch & Son, Leather Works, Sheepscar Street, Leeds.
T. R. Harding & Son, Tower Works, Globe Road, Holbeck.
William Ingham & Son, Fire-Clay Works, Wortley.
Joshua Tetley & Son, The Brewery, Hunslet Road, Leeds.
Wilson Walker & Co., Sheepscar Leather Works, Leeds.

Messrs. Joshua Buckton & Co., Well House Foundry, Meadow Road, Leeds.

These works stand on $3\frac{1}{2}$ acres of ground, and employ about three hundred hands. Here are made self-acting engineers' tools, heavy shearing machines, rail-finishing machinery, and special machines, such as testing machines and scale-beam dividing engines. A noticeable feature in these tools is the adoption of frames and

beds so constructed as to make the machines independent of their foundations, so that machines are tested before sending them out by simply connecting them by a strap to some of the works' shafting, or by means of the small special engine attached to the machine itself. Among the tools being made was a strong machine for paring the ends of steel rails accurately to length: also a very large planing machine, to plane 12 ft. 6 in. wide, and capable of carrying a casting weighing 30 tons. In the V bed of this machine a number of recesses are made at intervals and partly filled with oil; in each of these runs a pair of small wheels, which take up and distribute oil on the beds, as the travelling bed runs over them. The wear of the belt in heavy planing machines is overcome by placing a planed board under the strap, which is always more or less inclined, in such a position as to leave the strap perfectly free when tight, but to support it when at the time of the reversal it flaps about or tends to do so. The board is coated with a mixture of black-lead and tallow. This expedient has so reduced the breakage of straps that one machine has now been working for four years with a strap which had been rejected as not strong enough for it.

Messrs. John Fowler & Co.,
Steam Plough and Locomotive Works, Hunslet, Leeds.

The principal manufactures are steam-ploughing engines, traction engines, semi-portable engines for mining and other purposes, and portable railways with plant complete. Most of the steam-ploughing and traction engines at present in course of manufacture are on the compound principle. The portable-railway plant consists of locomotives of various sizes, from 4-inch cylinders upwards, and trucks both for passengers and for goods of every class; and of the railway itself, with its crossings, sidings, curves, &c. The works cover an area of above seven acres.

Messrs. Thomas Green & Son,
Smithfield Iron Works, North Street, Leeds.

These works were established in 1835. Their specialities are numerous, embracing vertical engines and boilers combined, and

Walker's three-cylinder engine and boiler for driving electric machines, &c., one of which was seen at work. They are also makers of Wilkinson's tramway engines, steam road-rollers, agricultural, horticultural, laundry, and domestic machinery; and are wire-workers, galvanisers, &c. They employ over 300 hands.

Messrs. Greenwood & Batley, Albion Works, Armley Road, Leeds.

These works stand on sixteen acres of ground, and were entered upon in 1864, the firm having removed from East Street. The drawing office is in a block of building to the left of the entrance gates. Close by is the pattern-making shop, with circular and band saws, wood-planing and saw-shaping machines, and wood-turning lathes. The foundry contains two 15-ton steam cranes for lifting the ladles, and for handling the castings, all the motions being done by steam power. Outside the foundry the large castings are dressed by manual labour; but adjoining is a shop where smaller castings are dressed by rotary machinery. About two tons per hour are thus cleaned by the process of friction, pieces of wood being intermingled to prevent breakage. In the planing shop, which comes next, were seen, amongst other work in hand, dynamo and letterpress printing machinery. In the adjoining erecting shop, 222 ft. long by 75 ft. wide, was seen dynamo machinery in another stage; also several specimens of bullet-making and small-arms machinery. Bullets are made by these machines at the rate of 100 per minute. There were also machines for punching discs and for making metallic cartridges, a board-drop hammer for stamping small forgings, trimming machinery, bolt and nut forging machines, and Ryder's forging machines for forging parts of guns. The smiths' shop contains three steam-hammers, one board-drop hammer, and other tools, including glaziers for polishing parts of textile machinery. The second erecting shop is 180 ft. long by 72 ft. wide, and contains band-saws for cutting iron cold, a large wheel-cutting machine, band-saw sharpening machines, slitting and milling machines, &c. In one compartment upstairs are 120 workmen making smaller tools, such as for small-arms, screwing, sewing, and other machines. The tools here employed are

similar to those below, but of lighter calibre. A gun-lock bedding machine, to make the recess in the stock for the gun-lock, a butt-plate bedding machine applicable to the end of gun-stocks, and a profiling machine, were specially to be noticed; also machinery for cutting leather into slips for belting, banding machinery requisite for gun-stocks, an efficient machine for turning and slitting heads of joiners' screws, and other machines for cutting the threads. With the latter machinery, from three to five screws can be turned out per minute, of average sizes. There were also machines for sewing with the waxed threads used by bootmakers; one size for sewing the uppers, and larger ones for sewing on the sole leather. These are also used for belting and harness work. In another part of the works is an office appropriated to drawings in connection with the manufacture of wool, silk, and china-grass machinery. Here also the small-arms machinery is brought to be tested, *i.e.* the tools and fixtures are carefully submitted to actual work. Another section of this room is filled with spinning and twisting or drawing and roving frames for silk manufacturers, and with screw-gill boxes for wool combers. In another division are small tools for making various parts of textile machinery. Altogether 1000 workmen are employed.

Messrs. Hathorn Davey & Co., Sun Foundry, Dewsbury Road, Leeds.

These works were established by Messrs. Carrett Marshall and Co., about thirty years ago, for the manufacture of pumping and hydraulic machinery. For the last ten years they have been in the possession of the present firm, and have turned out a large number of powerful pumping and hydraulic engines, both for water supply and for mining purposes, many of them on Mr. Davey's compound differential system; and also mining machinery of all kinds. There were in hand several large pumping engines, and a centrifugal pump for raising 100 tons of water per minute, which is to be used for draining purposes. A small steam motor with flashing boiler was on view; also an engine-recorder for pumping engines, which registers on a sheet of paper from day to day a complete chart of the working of the engine, and shows the quantity of water pumped during every hour of each day.

HUNSLET ENGINE CO.,
HUNSLET ENGINE WORKS, JACK LANE, HUNSLET.

These works make a speciality of locomotive tank-engines for narrow-gauge and light railways, also for contractors, ironworks, collieries, &c. One of MacColl's variable-power riveting machines is in use here, the only one at present in Leeds. Some bogie tank-engines, 3 ft. 6 in. gauge, for South Africa, with cow-catcher, spark-arresting chimney, and other accessories common on colonial engines, were seen finished.

MESSRS. KITSON & CO.,
AIREDALE FOUNDRY, HUNSLET ROAD, LEEDS.

These works were started thirty-six years ago, and now employ 1000 hands, and cover about seven acres. They are devoted mainly to the building of locomotive, stationary, and tramway engines, which, with a number of Parsons' high-speed engines, were seen in various stages of progress. Amongst the machine-tools in course of erection was a hydraulic riveting machine on Tweddell's system, for riveting up boiler shells vertically, having 12 ft. clear space between the riveting dies and the bottom of the jaws; it will give a squeeze of 40 tons with a water pressure of 1500 lbs. per sq. in. In another shop is a lathe to take in a 20-ft. wheel. In the machine and fitting shops are a large number of machine-tools with revolving cutters, including disc-wheels with cutters let into them, so as to form circular saws, for cutting out crank forgings, shaping forked joints, and other purposes. The electric light is largely used in the works, notwithstanding its costliness as compared with the cheap gas of Leeds. As a curiosity of old machinery may be noticed a punching and shearing machine by Joshua Buckton, made in 1848, which has stood the wear and tear of thirty-three years wonderfully well. The tramway engines made by the firm, with the valve-gear described in the Proceedings, 1880, p. 435, are now working successfully in Blackburn, Leeds, Glasgow, Edinburgh, and elsewhere.

MESSRS. SAMUEL LAWSON & SONS, HOPE FOUNDRY, MABGATE, LEEDS.

This foundry, established over seventy years since, covers an area of more than ten acres, and employs about 1400 hands.

Formerly the firm were spinners, as well as machine makers; but for the last thirty years they have confined themselves exclusively to making all classes of machinery for preparing and spinning flax, hemp, and jute, and for the manufacture of twines. They make also special machinery for preparing and spinning Manilla and other hemps for rope yarns.

Messrs. Manning Wardle & Co., Boyne Engine Works, Jack Lane, Hunslet.

Locomotive tank-engines form the speciality of these works, started in 1858; since which date a hundred various types of tank and other locomotive engines have been designed and constructed here for upwards of thirty different widths of gauge, and adapted where necessary for passing round sharp curves and ascending steep gradients. They are suitable for any climate, and for burning either coal or wood, as well as for all kinds of special duties. They are built to standard gauges and templates, to ensure interchangeable parts and correct duplicates. In course of construction are some steam tramway-engines, a number of which are already working satisfactorily.

Messrs. Scriven & Co. (late Scriven & Holdsworth), Leeds Old Foundry, Marsh Lane, Leeds.

These works were established in 1851 by the present owner, for he manufacture of machine-tools for iron-ship builders and engineers. They also make special machinery for boring and rifling the largest and heaviest class of modern ordnance, and had just supplied a second set of plant of the newest design for the Chinese government. Their new vertical plate-rolls bend the longest and heaviest plates for marine and other boilers to any radius or to a complete circle; the plates come out perfectly circular, without straight lengths at the ends. A double keel-plate bending machine bends at one operation both sides of the garboard strake of a plate-keel ship, and will also bend the garboard strake for bar-keel ships as well. A new side-light cutting machine was shown in operation, for cutting holes for side lights in ships after they have been plated, in order to get the holes into proper

position; it may also be used for cutting manholes and mudholes in boilers, and for similar work.

Messrs. Smith Beacock & Tannett, Victoria Foundry, Water Lane, Leeds.

These works formerly belonged to Matthew Murray, the maker of the original Blenkinsop locomotive (*ante* p. 268); and when the present firm took the place forty-five years ago, there were still remaining all the rails and the engine pit which Matthew Murray used in his engine building. The operation has recently been satisfactorily accomplished of throwing several of the original smaller shops into one large workshop, measuring 248 ft. by 146 ft., by taking down some of the old outside walls, and putting iron pillars and girders in their place. Here are made special tools of the largest kinds, particularly for marine-engine work; also Barrow's screwing machine for general screwing operations. There are about forty cranes, including five travellers worked by power. The large jib cranes in the foundry are worked by straps, and will lift 20 tons each. In one part of the works is a 30 horse-power beam-engine, sixty years old, of Matthew Murray's make, which drives half the tools in the shops. A 50-ton travelling crane was under construction; also a lathe for ordnance, 75 ft. by 9 ft., and weighing 80 tons.

Messrs. Tannett Walker & Co., Goodman Street Works, Hunslet, Leeds.

These works have been in existence twenty years, and stand upon ten acres. All the heavy machinery used in the manufacture of iron and steel is made here, such as Bessemer and Siemens plant; rolling-mill machinery; large and small steam-hammers; machines for shearing, punching, &c.; hydraulic machinery, such as pumping engines, accumulators, tanks, cranes, hoists, capstans, and swing-bridges; and all dock and warehouse machinery. Over one of the large erecting shops is a rope travelling-crane fitted with worm gear and pitch pulleys, and driven by a separate engine. In the

works is hydraulic machinery for hauling heavy weights. Very large castings can be made; and there is a deep pit in which hydraulic cylinders and rams up to 30 tons weight and 50 feet in length can be cast. A 30-ton steam jib-crane commands this pit, which is kept in constant operation for large hydraulic cylinders and rams, required in the Bessemer and Siemens processes; all of these are made from the best selected cold-blast and hæmatite iron, and are cast with a large rising head. A large pair of compound rail-mill reversing engines was just completed, with two high-pressure cylinders of 34 inches diameter, and two low-pressure of 60 inches diameter, all 5 feet stroke. A large pair of compound Bessemer blowing engines with surface-condensers was also just completed; both high and low-pressure cylinders were fitted with expansion-valves. Twelve hydraulic four-cylinder capstan engines were making here for H.M. Dockyard at Chatham, each capable of exerting a pull of 16 tons at the rate of 30 feet per minute, and 8 and 4 tons at higher speeds, working at a pressure of 700 lbs. per sq. in. There were also several machines for a Bessemer steel works, a complete arrangement for tipping large converters by hydraulic power, and hydraulic machinery for the Cheshire Lines goods warehouses, and for the Great Northern Railway premises in London, &c. A number of ingot cranes on Mr. Walker's balance principle (Proceedings 1881, p. 633) were making for the Bessemer and Siemens processes, or for foundries.

Messrs. Joseph Whitham & Son,
Perseverance Iron Works, Kirkstall Road, Leeds.

This firm are makers of steam engines of all descriptions, with compound cylinders and automatic cut-off expansion gear, or on the Corliss principle; also deep-lift pumps, plant for blast-furnaces, steam-boilers of all kinds, and wrought-iron girders and tanks. Oil-mill machinery, both for the old and new processes, is produced here: the first hydraulic oil-presses ever used having been made by this firm. Iron is also made by Whitham's Puddling Machine; and there is a forge and mill for ship and boiler plates, angles, &c.

Farnley Iron Works, Farnley.

These works, which have been in existence about forty years, were founded by four brothers, one of whom, Mr. William Armitage of Ainderby Hall near Northallerton, still survives. The whole of their produce is from the minerals raised on the estate. The ironstone, with the Black-Bed coal (see Mr. Meysey-Thompson's paper, *ante*, p. 275–6), occurs at various depths, and is raised from five pits; the ore contains about 30 to 33 per cent. of metallic iron. The coal used for smelting is not the Black-Bed seam worked with the ironstone, but the Better-Bed seam, which occurs about 40 yards below the stone, and is all made into coke for smelting. The ironstone is calcined, and cold blast is used for the blast-furnaces. As only the highest quality of best Yorkshire iron is made at these works, the processes of refining and puddling, and the manufacture of blooms, bars, slabs, boiler-plates, and forgings, are carried on here in precisely the same manner as at the Lowmoor and Bowling Works. The Farnley Works produce plates of exceptionally large size. A large rolling-mill designed by Mr. Gillott, and put to work six years ago, has rolls 31 in. diameter and 11 ft. long, in which a number of plates have been rolled, some of them 10 ft. square, and others 10 ft. 8 in. diameter. There is a smaller plate-mill with rolls 24 in. diameter; an 18 in. bar-mill; and an 8-in. guide-mill. There are nine steam-hammers of large size, and a tyre-mill for the production of weldless tyres. The engineers' department is provided with tools for finishing the flanged work, executing new work, and doing the whole of the repairs required in the works. In the foundry are made the whole of the castings needed. Gas furnaces are largely used for heating. Underneath the Better-Bed coal used for smelting is a bed of fire-clay (Plate 50), from 2 ft. to $2\frac{1}{2}$ ft. thick, which is workable in most cases when the depth below surface does not exceed 70 yards; and the fire-brick trade at Farnley, with its allied products, is probably of equal importance with the iron manufacture. Sanitary tubes, gas retorts, chimney-pots, fire-bricks and lumps, have been made here for a great number of years; and more recently the manufacture on a large scale of glazed and ornamental bricks has been carried on with great success, the high quality of the coal and of the clay largely

contributing to this result. The works occupy an area of about sixty acres. From the raising of the raw material to the turning out of the finished bars, plates, forgings, bricks, and earthenware goods, the whole of the processes are carried on at the works; and material found at Farnley is almost exclusively employed.

Kirkstall Forge Co., Kirkstall Forge, near Leeds.

These ironworks are not far from the ruins of the famous Kirkstall Abbey, founded A.D. 1152 for monks of the Cistercian Order; and are among the oldest ironworks in the country. They were established in the family of the present proprietors, the Messrs. Butler, in 1779. The works cover an area of about fourteen acres; about a thousand is the full complement of workmen. Here are made railway tyres and axles, crank-axles, forgings, bar iron, angles, &c., of "Best Yorkshire" iron, manufactured solely from cold-blast pig, refined and selected; also merchant iron in different qualities, and steel bars and forgings. The principal speciality is rolled shafting, which has proved a very successful manufacture. This shafting is made from carefully selected pig-iron; and after being worked and rolled in the ordinary manner, is taken while still hot from the rolls, and passed through the patent straightening and planishing machine, which compresses the iron, removes all scale, gives it a smooth finished surface, and leaves it in all essentials equal to ordinary turned iron. The effect of this process on the iron is to add greatly to its strength and rigidity, so that it shows 20 per cent. more elastic torsional strength, and 30 per cent. more elastic flexional strength, than shafting rolled only in the ordinary manner. Another speciality is Butler's frictional coupling, which has been brought out specially for the above-named shafting. It requires no keys, nor any fitter's work, and holds entirely by friction; and as in fixing it closes up concentrically, it ensures true and accurate running of the shafting.

Messrs. John Barran & Sons, Wholesale Clothing Manufactory, Park Square, Leeds.

This firm was established in 1855, for the manufacture of clothing by machinery (see Mr. Meysey-Thompson's paper, *ante*, p. 272).

In the basement are numerous machines cutting out suits, the motive power being obtained from two of Crossley's silent gas-engines, one of 16 and the other of 8 horse-power; these are also used for driving the hoist and the sewing machines on the top floor of the building. On the first floor is a stock of clothing of all sizes and shapes. On the next floor are the pressing machines, heated by gas. In the top storey are 300 sewing machines, all in one room, which is lighted from above. Intricate designs in braiding are done here with wonderful precision and speed. The number of workpeople employed at present is nearly 2000.

Messrs. J. J. Flitch & Son,
Leather and Glue Factory, Buslingthorpe, Leeds.

These works, established in 1850, carry on the several processes of unhairing, liming, fleshing, paring, tanning, dyeing, shaving, and finishing most descriptions of leather, more especially the better classes for fancy goods, such as russia, morocco, calf, &c. By the aid of several labour-saving appliances, about one thousand dozen skins are turned out per week, or about half a million per annum. These works were amongst the first to introduce the electrotype process in embossing skivers, which enables an almost endless variety of grains and surface markings to be produced. They import largely russia hides, which are dyed and finished in various colours, to be used principally for binding books and for fancy leather goods.

Messrs. Joshua Tetley & Son,
The Brewery, Hunslet Road, Leeds.

The original brewery was started about half a century ago; and the present one, commenced in 1855, now covers an area of over six acres. Two new cast-iron mash-tuns have been erected by Messrs. Kitson & Co. (in addition to four previously in use): one of these is 17 ft. diam. in a single piece, and the other is 18 ft. diam. in sections. The total mashing power is 225 quarters per day. There are two large steam coppers, of 14 and 15 ft. diam., in addition to four older ones boiled by fire. The fermenting vessels, 141 in number, are all on the Yorkshire square system, most of them of slate, erected by

Messrs. Alfred Carter & Co. There are two of Riley's helical refrigerators, capable of cooling 120 and 140 barrels per hour down to within 4° Fahr. of the temperature of the cooling water used. Hydraulic machinery, supplied by Sir William Armstrong & Co., is used for working five piston-hoists and five chain-hoists, for passengers and goods, and five sack-hoists. In the new maltings the grain is distributed by elevators and by an india-rubber carrying band, with discharging appliances; which were also supplied by Sir William Armstrong & Co. There are ten large boilers supplying steam to eleven engines of various sizes, and of about 200 aggregate nominal horse-power. One engine drives a machine for producing cold by the vaporisation of ether, but none of the past three summers have been sufficiently hot to require its use; the shafting in the brewhouse can also be driven by the same engine. Steam is also largely used for heating, boiling, and washing purposes. The supply of water for brewing is obtained from a well 90 ft. deep and 25 ft. diam. at the bottom, and greatly resembles the Burton water. The water used for cooling and washing purposes is obtained from two artesian wells, 600 ft. deep. The firm do the principal part of their own malting, and manufacture and repair on the premises their own casks, drays, &c.; and employ altogether over four hundred hands. The casks are all washed by machinery, which does away with the necessity of unheading and heading up again.

Messrs. Wilson Walker & Co., Sheepscar Leather Works, Leeds.

This business was established in 1823 by the late John Wilson, and the present works, built in 1847, give employment to over 350 hands. Calf kid, tanned calf, sealskin for boot purposes, sheepskin, &c., are all made up into the various kinds and qualities of leather; and 3000 skins per day are easily turned out in the various forms of roans, chamois, &c. The calf-kid department consumes 200,000 skins annually. In the processes of dyeing, shaving, and finishing, many ingenious time-saving appliances are introduced. The bulk of the leather here manufactured is used by upholsterers, coach and carriage builders, bookbinders, shoemakers, &c.

WORKS AT BRADFORD.

MESSRS. THWAITES BROTHERS (late THWAITES & CARBUTT), VULCAN IRON WORKS, THORNTON ROAD, BRADFORD.

These works were established in 1855, and employ about 200 hands. They consist of a turning shop, fitting shop, smithy, store-rooms, and pattern shop; and cover a ground area of about two acres. The turning shop, which is 224 ft. long by 33 ft. wide, is filled with lathes capable of boring out cylinders up to 100 inches diameter; planing machines, of which one, a side planer, can plane to a height of 10 ft.; powerful drilling and slotting machines, &c.; and overhead run powerful travelling cranes, one of which can lift 30 tons. The fitting shop, which is 152 ft. long by 56 ft. wide, is devoted principally to the fitting and erection of steam-hammers; for this purpose a pit is sunk in it, so as to leave room above for the travelling crane, which is constructed to lift 50 tons, and to pass over the tops of the steam-hammers. In the smithy, which measures 56 ft. by 42 ft., are eight blacksmiths' fires, supplied with air by a No. 2 Root's blower, a 12-cwt. cast-standard self-acting hammer, and a 6-cwt. single-standard double-framed hammer, also fitted with a self-acting valve-motion; also a punching and shearing machine, &c. The specialities of this firm consist of steam-hammers, blowers and exhausters, rolling-mill engines, punching and shearing machines, straightening and bending machines, hot saws, and all the plant used in iron and steel works. Of steam-hammers upwards of eight hundred have been turned out, some being of the largest size: such as one of 35 tons, which in 1869 was converted to 50 tons, for Capt. Kolokoltzoff's Alexandrovna Works, for forging gun-coils; and another of 30 tons supplied to Sir William Armstrong & Co. for the same purpose. In 1867 was commenced the manufacture of Root's blowers and exhausters, of which upwards of four thousand have been made, to produce a blast of air varying between that from a fan and that from a blowing engine. Some of them are built with a duplex engine, both blower and engine being mounted upon a strong

cast-iron bed-plate. In large sizes these machines are arranged as mine ventilators (see Proceedings 1877, p. 92); one of which has been working with great success since 1877 at Chilton Colliery, Ferry Hill, Durham. Air-compressors also have latterly been made here, to run at high speed, which possess several advantages over those of ordinary construction.

Messrs. Lister & Co., Manningham Silk Mills, Bradford.

These mills, re-erected ten years ago, cover an area of nearly twelve acres. The combined driving power for the works is equal to 3260 HP. There are seven engines, namely a pair of high-pressure horizontal compound condensing engines of 1400 IHP.; a pair of beam engines of 1000 IHP.; a horizontal high-pressure compound condensing engine of 400 IHP.; a vertical condensing engine of 300 IHP.; two pairs of high-pressure horizontal engines of 60 IHP. each; and a vertical high-pressure engine of 40 IHP. The pair of beam engines were built by the Bowling Co. over thirty years ago, for working steam expansively. A vertical driving-shaft of 40 tons weight, running at 112 revolutions per minute on a foot of 13 inches diameter, was tried at first with cast-iron and wrought-iron steps, which proved unsuccessful under such a load; Whitworth compressed-steel and phosphor-bronze were then substituted, and have answered perfectly.

Messrs. Daniel Illingworth & Sons, Whetley Mills, Thornton Road, Bradford.

The machinery is all driven by ropes from an engine constructed by Messrs. Hick & Hargreaves, of Bolton, with 40-inch cylinder, 10-feet stroke, and Corliss valves. The driving ropes run on the rim of the fly-wheel, which is 30 ft. diameter and weighs 58 tons. This engine has been at work about two years.

WORKS ETC. AT HULL.

LIST OF WORKS ETC. THROWN OPEN TO THE INSTITUTION.

Town Hall, Lowgate.
Holy Trinity Church, Market Place.
St. Mary's Church, Lowgate.
Wilberforce House, &c., High Street.
Royal Institution, Albion Street.
Trinity House, Trinity House Lane.
Works of the Alexandra Dock (under construction).
West Docks, with extension under construction.
Humber, Prince's, Queen's, and other Docks.
Earle's Shipbuilding and Engineering Works.
Messrs. Amos & Smith, Engine Works.
Messrs. C. D. Holmes & Co., Engine Works.
Messrs. Priestman Brothers, Engine Works.
Messrs. Rose Downs & Thomson, Seed-Crushing Machine Works.
Hull Forge Co.'s Works.
Hull Hydraulic Power Co.'s Works.
Kingston Cotton Mill.
Messrs. W. Gray & Co., Seed-Crushing Works &c., Church Street.
Messrs. Ellershaw & Sons, Seed-Crushing Works &c., Sculcoates.
Messrs. Gleadow & Dibbs, Brewery.

Hull Docks.

[The following particulars as to the gradual development and present position of the Hull Docks have been kindly furnished by Mr. R. A. Marillier, M. Inst. C.E., Docks Engineer.]

The Dock Company have at present seven docks, the first of which was opened in 1778 and the last in 1880. They have also two timber ponds and a large graving dock. The dates of the construction of the various docks, their dimensions, and areas are as follows:—

Date of opening.	Length. Feet.	Breadth. Feet.	Area. A.	R.	P.
Queen's Dock, 1778	1703	254	9	3	29
Basin	211	80	0	1	22
Lock	121	38		—	
Humber Dock, 1809	914	342	7	0	24
Basin	258	320	2	1	19
Lock	158½	41½		—	
Prince's Dock, 1829	645	407	6	0	5
Lock	120	35½		—	
Railway Dock, 1846	720	165	2	3	9
Lock	—	42		—	
Victoria Dock, 1850	2,015	378	20	0	4
Basin (Outer Harbour)	318	348	2	3	7
Half-tide Basin	293	348	3	0	0
Drypool Basin	315	145	1	0	8
Drypool Outer Basin	220	150	0	1	32
Old Timber Pond	—	—	13	3	4
New Timber Pond	—	—	11	0	15
Albert Dock, 1869	3,418	430 & 200	24	2	18
Basin	—	—	1	3	37
William Wright Dock, 1880	1,390	220	5	3	37

The docks have altogether a water space of upwards of 88 acres, exclusive of the timber ponds, which are nearly 25 acres in area. Another dock, 10½ acres in area, is in progress, provision being made to extend it to 23 acres when found necessary. This dock is expected to be opened at the beginning of next year. The total water space with the projected extensions will be nearly 138 acres.

The graving dock, the entrance to which is in the William Wright Dock, is capable of taking in the largest ships coming into the port. Its dimensions are as follows:—

	Feet.
Length from gates to head	501
Length on blocks	460
Width at the top	85
Width of entrance	50

Another graving dock of nearly the same size is now in course of construction, the entrance to which will be in No. 2 New West Dock.

Alexandra Dock Works, Hull.

The Alexandra Dock works are situated to the east of Earle's Shipbuilding yard, and extend over a very large area. Some two thousand men are at present employed, principally in excavating and walling; they are working night and day shifts, and with the assistance of the steam navvies, cranes, &c., are getting out fully 120,000 cubic yards per month. When the works are completed there will be $1\frac{1}{2}$ mile of dock walling, and a similar extent of sea wall. The hydraulic engine-house is now complete, and working cranes and a hydraulic navvy. Rails are laid over the whole workings, twenty locomotives being in constant use; and seventy other engines are at work for other purposes, such as driving steam-cranes, pumping, pile-driving, &c. The electric light is used at night. The dimensions of the docks are as follows:—Main Dock, 2300 ft. long by 1000 ft. wide, water area $46\frac{1}{2}$ acres; Graving Dock, No. 1, 500 ft. long, with 60 ft. width at entrance; No. 2, 550 ft. long, with 65 ft. width at entrance. The main lock is 550 ft. long and 85 ft. wide, with 34 ft. depth on sill at high water of spring tides, and 27 ft. 10 in. at neaps.

Earle's Shipbuilding and Engineering Works, Hull.

These works have been carried on for upwards of thirty years; they cover an area of about thirty acres, and do the whole of the work in connection with the construction of ships and their engines. The yard is situated on the banks of the Humber, here three miles wide, and has a good river frontage with plenty of water, so that the largest ships can be launched without hindrance. To the west of the yard is the Victoria Dock, and on the east the Alexandra Dock now in course of construction; there is thus water accommodation on three sides. The works possess facilities for executing the most extensive repairs expeditiously, having four slips, two worked by hydraulic gear and two by steam. The last constructed hydraulic slip has only been in use a few months, and is the largest in

England, being capable of hauling up a ship of 3500 tons gross register, that is, a dead weight of 2500 tons, in an hour and a half. The other hydraulic slip is adapted to take up ships of 2000 tons dead weight.

Hull Hydraulic Power Co.

The supply of motive power by hydraulic pressure, on the system inaugurated by Sir William G. Armstrong, was commenced here in 1875. About $1\frac{1}{4}$ mile of 6-inch mains has been laid through the streets bordering the old harbour, where most of the wharves and warehouses are situated, and hydraulic power is supplied to a large number of premises for various purposes. An important extension now in progress will complete the circuit round the docks, and will enable new connections to be made or repairs to be effected without inconveniencing other consumers. At the pumping station in Machell Street are two pairs of engines, together of 60 horse-power, each pair having cylinders $12\frac{1}{4}$ in. diameter by 2 ft. stroke, driving the pumps direct, and delivering into the accumulator 135 gallons of water per minute at the pressure of 700 lbs. per sq. in. The accumulator is 18 in. diameter, with 20 ft. stroke, containing 220 gallons of water, and weighted with 80 tons of slag. Over the engine room is a cast-iron tank containing 44,000 gallons of water, which is pumped from the river Hull at low water by two duplicate 8-in. Appold centrifugal pumps, driven by a Brotherhood three-cylinder engine—each pump being capable of delivering 48,000 gallons per hour to the height of 35 feet, when running at 800 revolutions per minute. The Hull Dock Co. have laid a main of their own along the Queen's Dock, and are renting power from the Hydraulic Power Co. for working the cranes and other lifting appliances at that dock.

Institution of Mechanical Engineers.

REPORT ON THE NORTH-EAST COAST EXHIBITION OF MARINE ENGINEERING, &c.

[At a meeting of Council held at Leeds on 15th August, Mr. F. C. Marshall (Member of Council) presented on behalf of the Committee of the North-East Coast Exhibition of Marine Engineering, Fishery, Life-Saving and Coast-Lighting Appliances, an invitation to appoint representatives of the Institution of Mechanical Engineers, who should attend the opening ceremony of the Exhibition at Tynemouth on 6th September. The Council thereupon appointed as delegates Mr. Jeremiah Head (Vice-President) and Mr. George B. Rennie (Vice-President). These gentlemen attended accordingly, and subsequently presented the following report, which was read at the meeting of Council, Oct. 13th, and a resolution passed that the same should be printed in the Proceedings of the Institution.]

TO THE COUNCIL OF THE INSTITUTION OF MECHANICAL ENGINEERS.

GENTLEMEN,—We have the honour to report that, agreeably to the resolution passed at the Council Meeting held at Leeds on the 15th August,—"That on the invitation of the Board of Management of the North-East Coast Exhibition of Marine Engineering, Fishery, Life-Saving and Coast-Lighting Appliances, Mr. Jeremiah Head (Vice-President) and Mr. George B. Rennie (Vice-President) should be appointed delegates to represent the Institution at the opening of the above-named Exhibition on the 6th September"—the undersigned attended accordingly on the day named at Tynemouth, where the Exhibition took place. We need hardly say that every attention was paid to your deputation, and we were presented to the President of the North-East Coast Exhibition at the opening ceremony. As regards the Exhibition itself, we cannot but express our admiration of its admirable arrangements, and of its valuable and interesting collection of Exhibits.

The collection of Ship Models was the best (especially as regards the Mercantile Marine) that it has been our good fortune to have seen brought together.

There were some excellent specimens of Marine Engines, such as those of the horizontal type, as made by Messrs. R. & W. Hawthorn for H.M.S. *Dolphin* of 750 I.H.P., and of the vertical type in the treble expansive engines of 500 I.H.P., made by Messrs. Wigham Richardson and Co.

A line of steel shafting of $12\frac{1}{2}$ in. diameter, made by Messrs. Krupp of Essen for Messrs. R. & W. Hawthorn, was well worthy of inspection. The end length of shafting was in one piece 48 ft. 6 in. long, with a hole $4\frac{1}{2}$ in. diam. bored up the whole length,—an excellent piece of work. This example was a good illustration of what can be accomplished on the Continent, and showed the advantages of such exhibition. The various specimens from Steel Works, showing what can now be done with that material, in its cast, rolled, or forged form, were well worthy of notice, as evidence of the extent of its application for various mechanical purposes, and how it seems to be superseding iron in many ways.

An interesting historical exhibit was a Locomotive in working order of one of the early colliery types, with vertical cylinders and connections to the driving wheel. It was called the "Wylam Dillie," and was said to have been made by W. Hedley in 1813.

The various improvements and applications of Mechanical appliances in connection with Marine Work were highly instructive to the mechanical engineer.

The Fishing and Life-Saving exhibition also illustrated the importance of mechanical knowledge, in contriving the different appliances for such like industries.

Models of Harbours, Lighthouses, and the mechanical means that were being adopted for their construction, deserved much attention,—such as the large Gantry Cranes used for transporting the concrete blocks, in constructing the Tyne Harbour Piers; also models of Dredging Machines &c. This latter class of machinery having played such an important part in the improvements of the river navigation of the Tyne, it may be interesting to quote what has been

done. According to the chart made from the survey under Mr. Rennie's direction in 1813, there was only a depth of water of 6 ft. over the bar at low water, and only 4 ft. channel up to Newcastle. About the year 1860, Mr. Ure, the Engineer of the Tyne Commissioners, recommended the construction of very powerful dredgers to deepen and widen the channel. This plan has been carried out with such excellent results, that about 5¼ millions of tons have been excavated and carried out to sea annually, which has resulted in giving an average increase of about 20 ft. of water as far up the river as the Newcastle bridge. It forms a most remarkable instance of a river being materially improved as a navigable stream by mechanical means.

There were doubtless many other valuable exhibits to be seen, which our limited time would not permit us to inspect.

We have thought a general outline description of the impression made upon us would be acceptable to you, and in conclusion we beg to hand in a copy of the catalogue, which may be serviceable in the Library for future reference.

(Signed) JEREMIAH HEAD,
GEORGE B. RENNIE.

ENGINEERING IN LEEDS.

Fig. 1. *Blenkinsop Locomotive.*

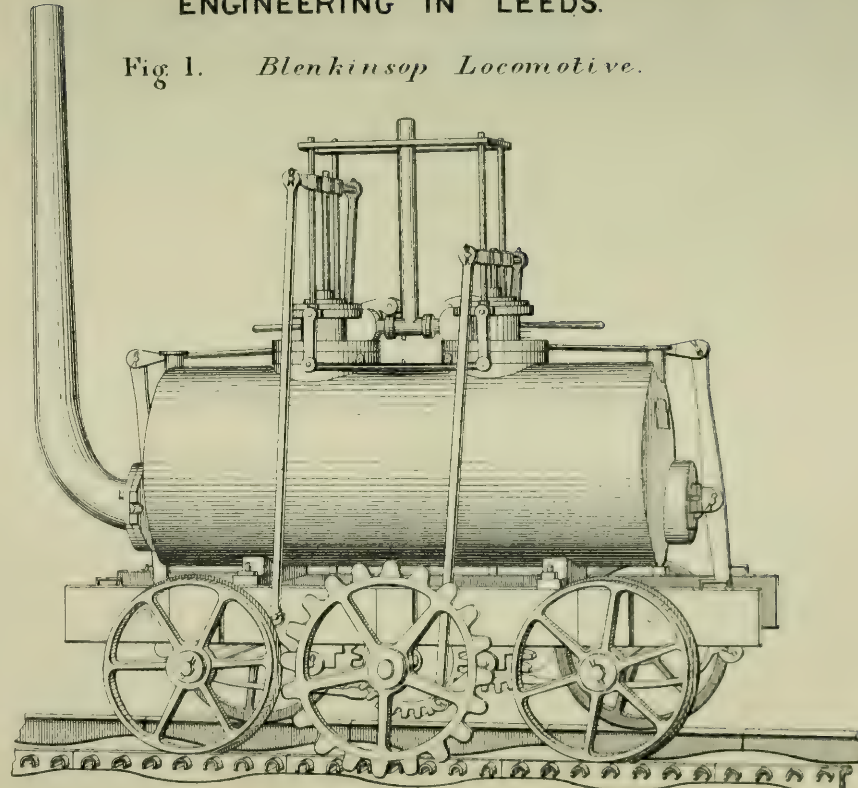
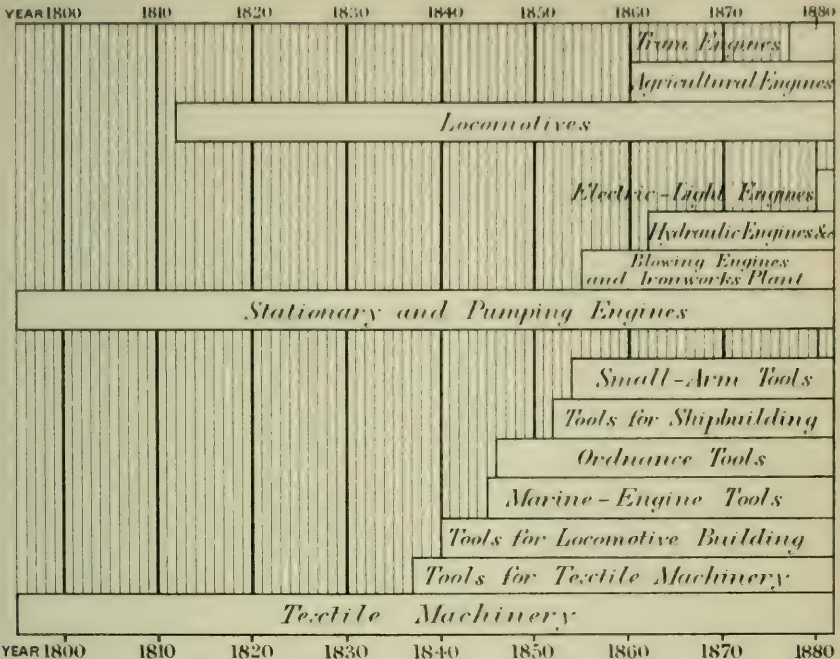


Plate 47.

Fig. 4. Chart of Engineering Trades



Killingworth Locomotive.

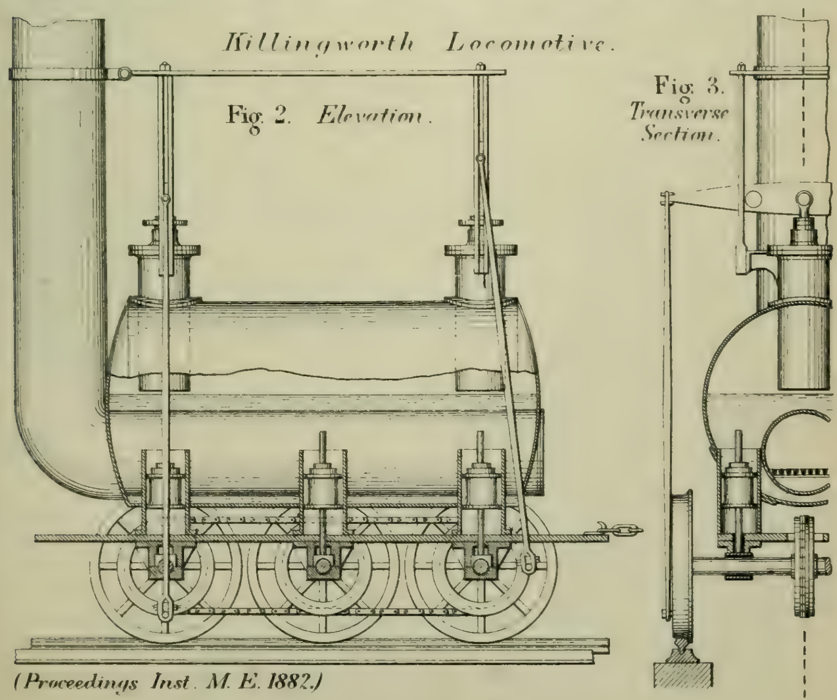
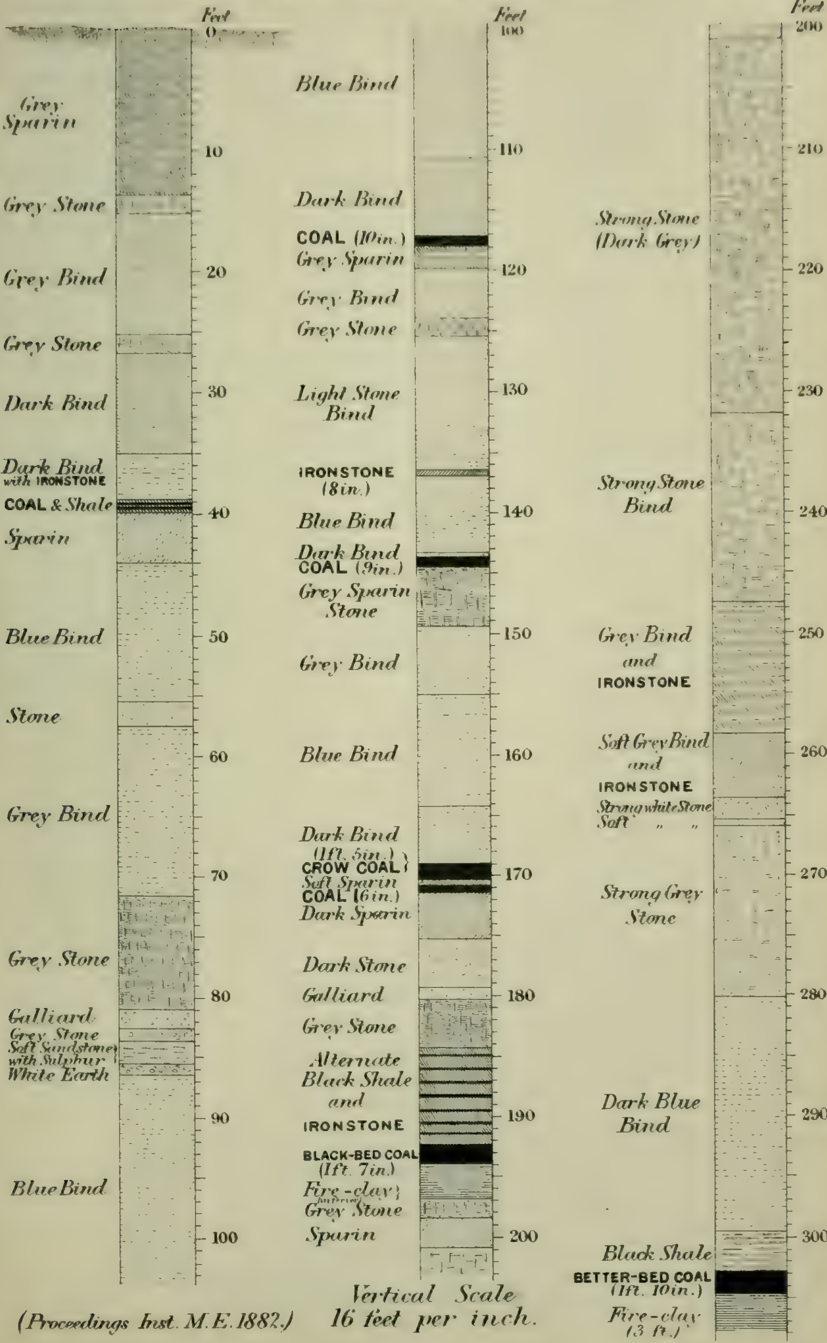


Fig. 2. Elevation.

Fig. 3. Transverse Section.

(Proceedings Inst. M. E. 1882.)

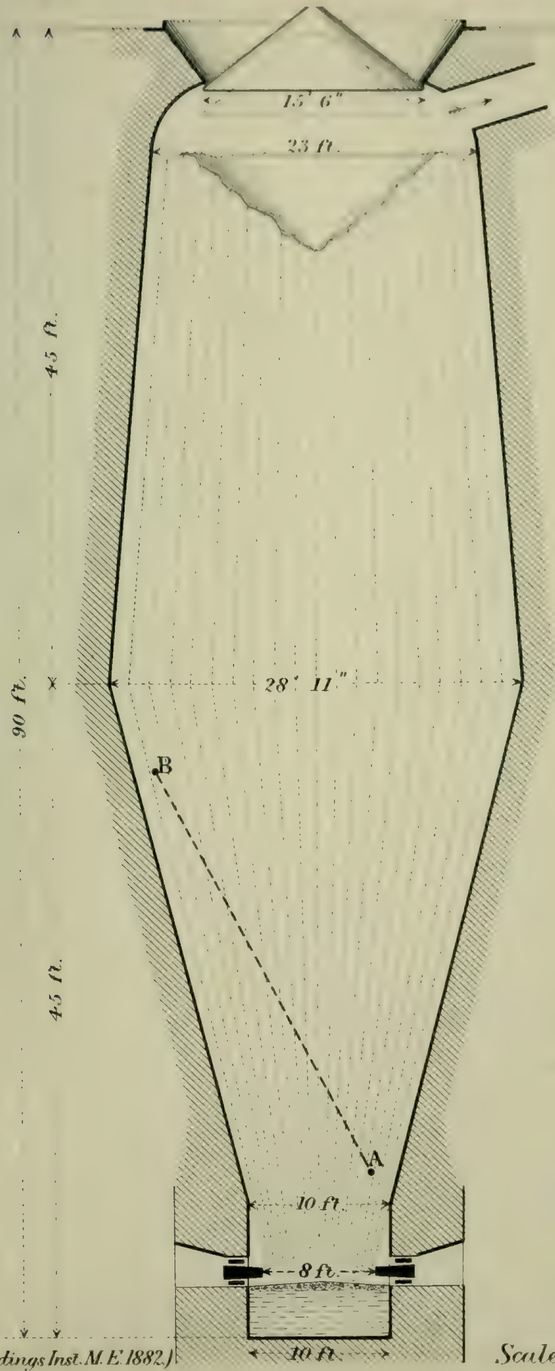
Fig. 6. *Section of Sinkings to Low-Moor Better-Bed Coal.*



(Proceedings Inst. M.E. 1882.)

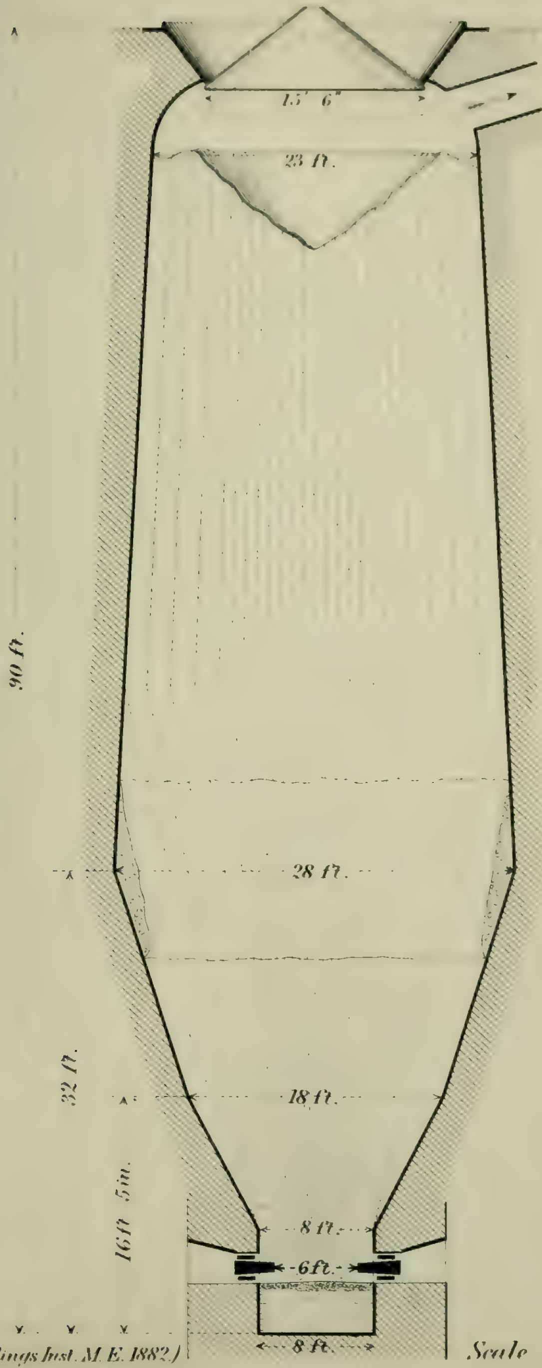
Vertical Scale 16 feet per inch.

Fig. 1. *No. 1 Furnace, 33400 cubic feet.*



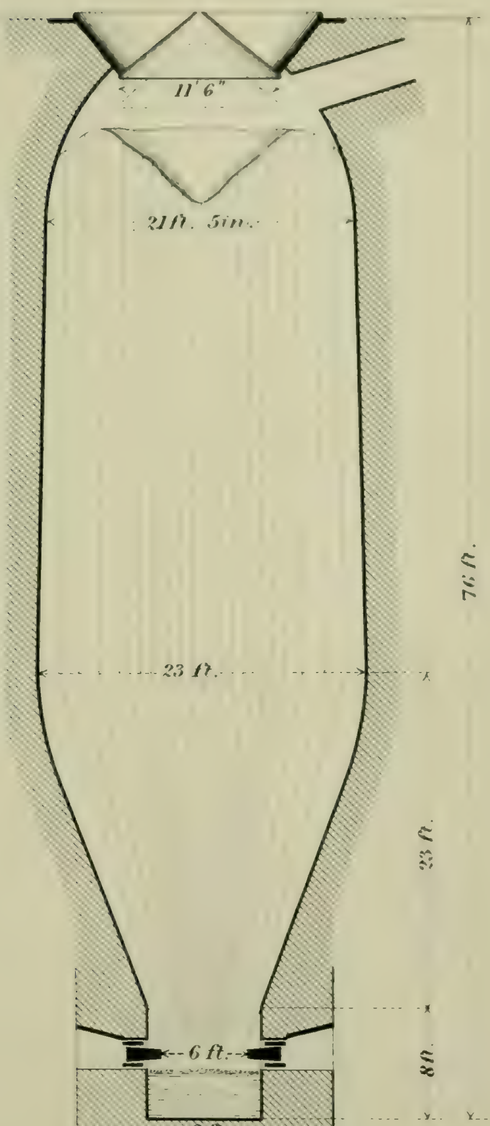
(Proceedings Inst. M. E. 1882.) *Scale 1 to 160.*

Fig. 2. *No. 2 Furnace. 35013 cubic feet.*



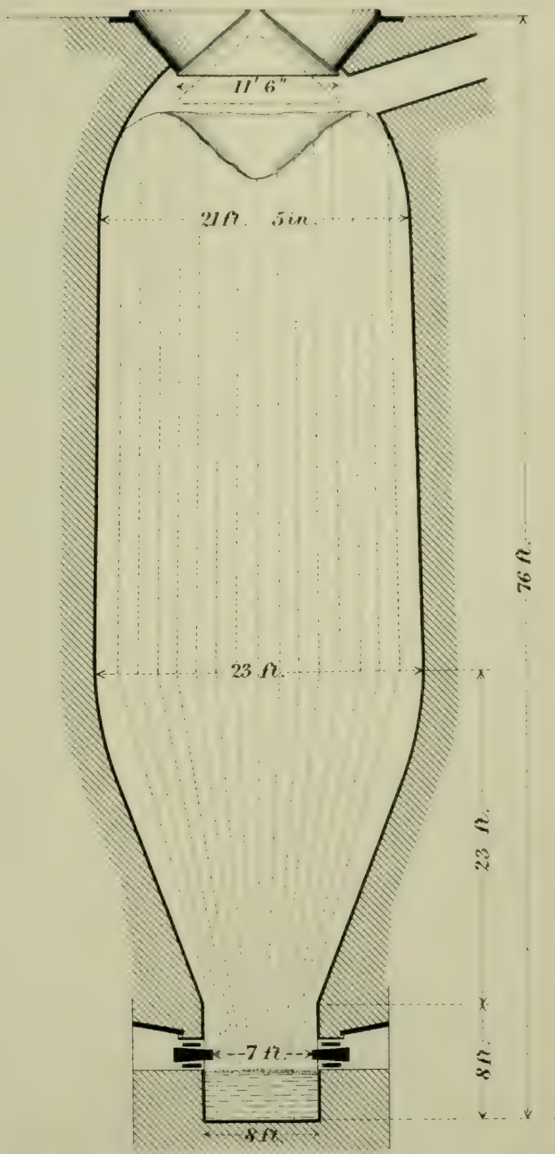
(Proceedings Inst. M. E. 1882.) *Scale 1 to 160.*

Fig. 3. *No. 3 Furnace,*
Capacity 20454 cubic feet.



(Proceedings Inst. M. E. 1882.) *Scale 1 to 160.*

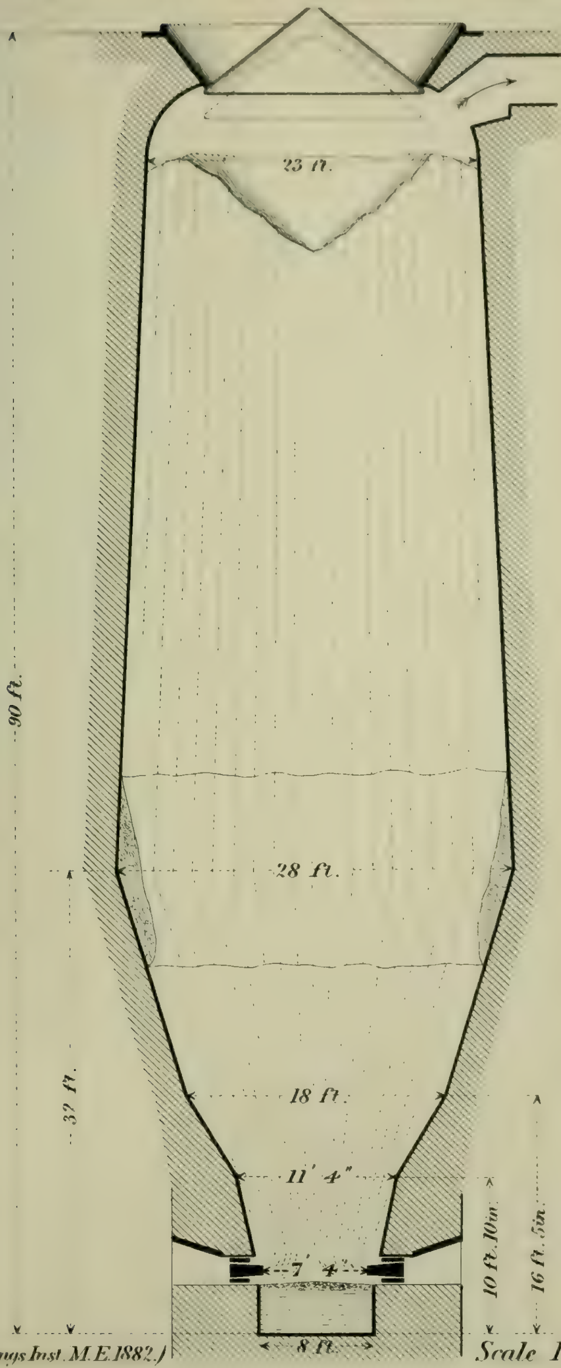
Fig. 4. *No. 4 Furnace.*
Capacity 20454 cubic feet.



(Proceedings Inst. M. E. 1882.)

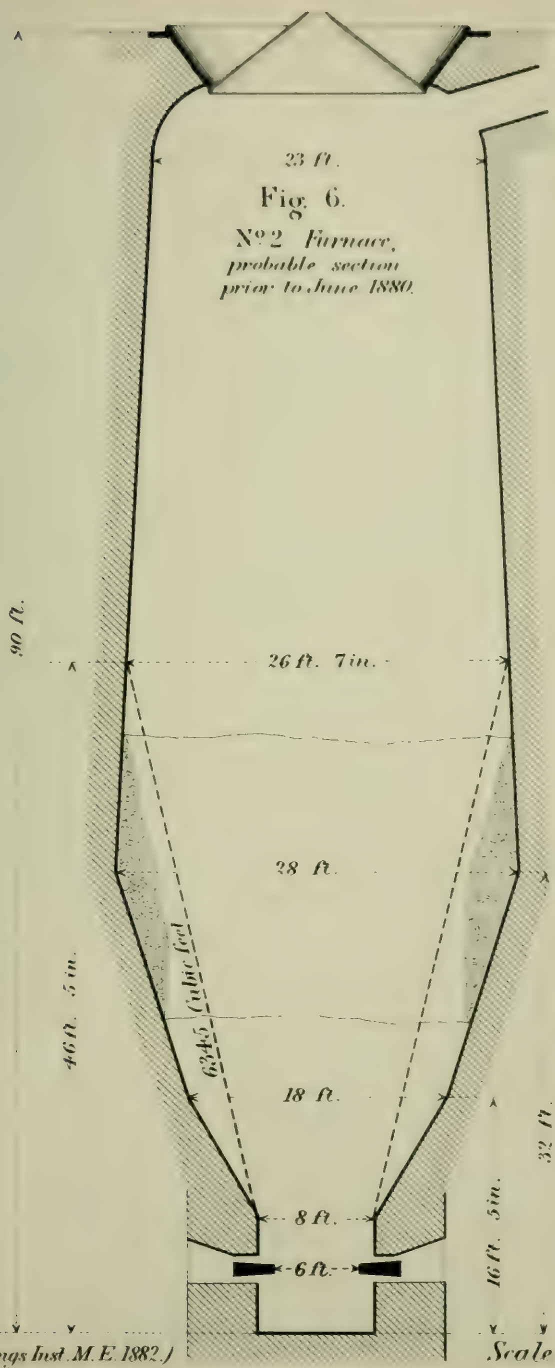
Scale 1 to 160.

Fig. 5. No. 2 Furnace, 35117 cubic feet.



(Proceedings Inst. M.E. 1882.)

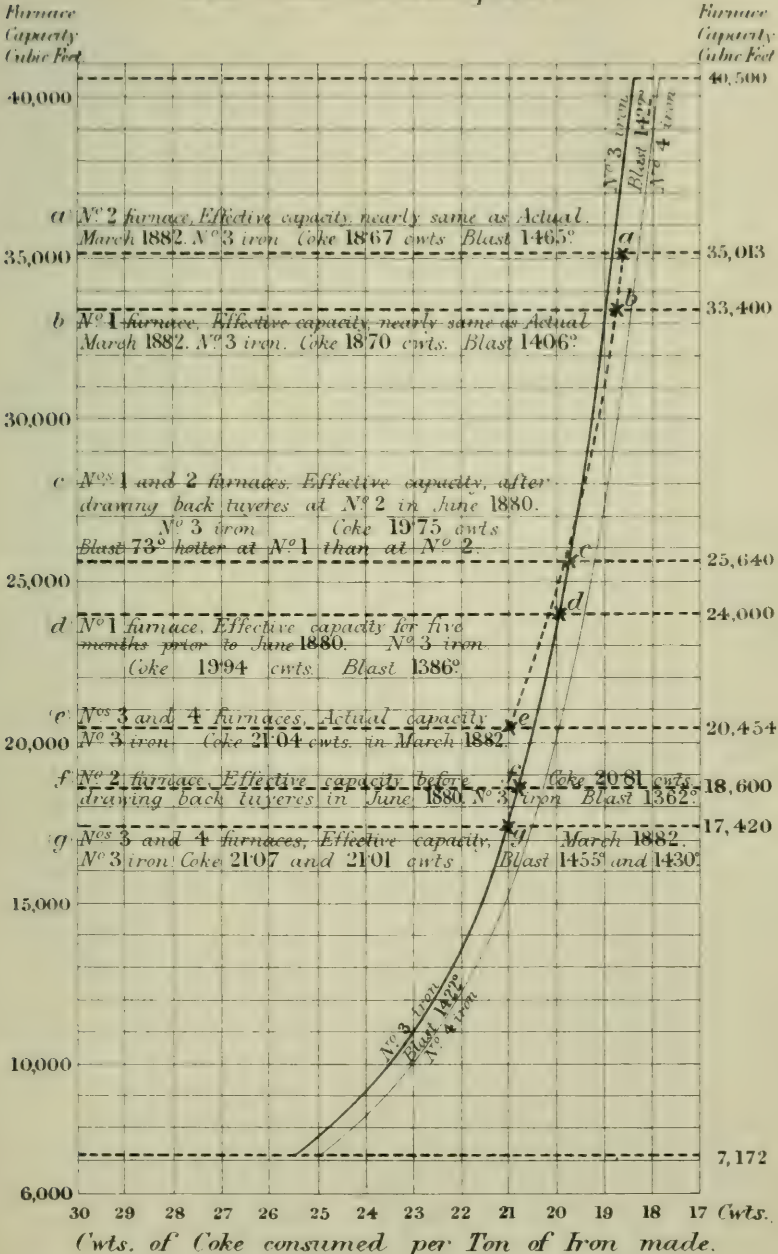
Scale 1 to 160.



(Proceedings Inst. M. E. 1882.)

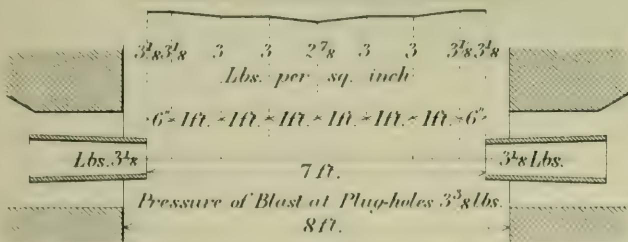
Scale 1 to 160.

Fig. 7. *Curve of Furnace Capacity and Coke Consumption.*



(Proceedings Inst. M. E. 1882.)

Fig. 11. *Blast Pressure, No. 4 Furnace.*



Intensity of Temperature in Hearth.

Fig. 9. *Overhang 6 inches.*

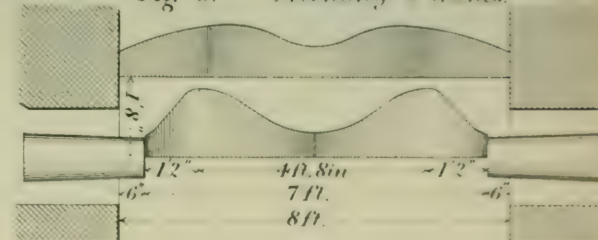


Fig. 12. *Blast Pressure, No. 1 Furnace.*

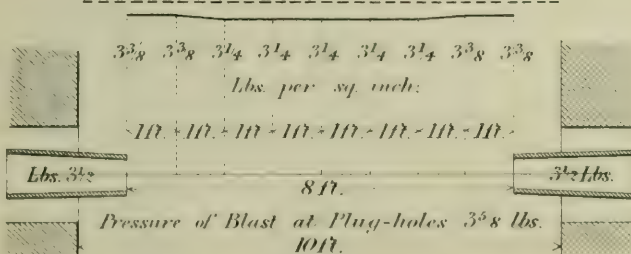


Fig. 10. *Overhang 12 inches.*

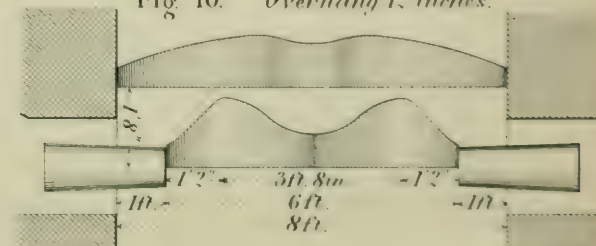
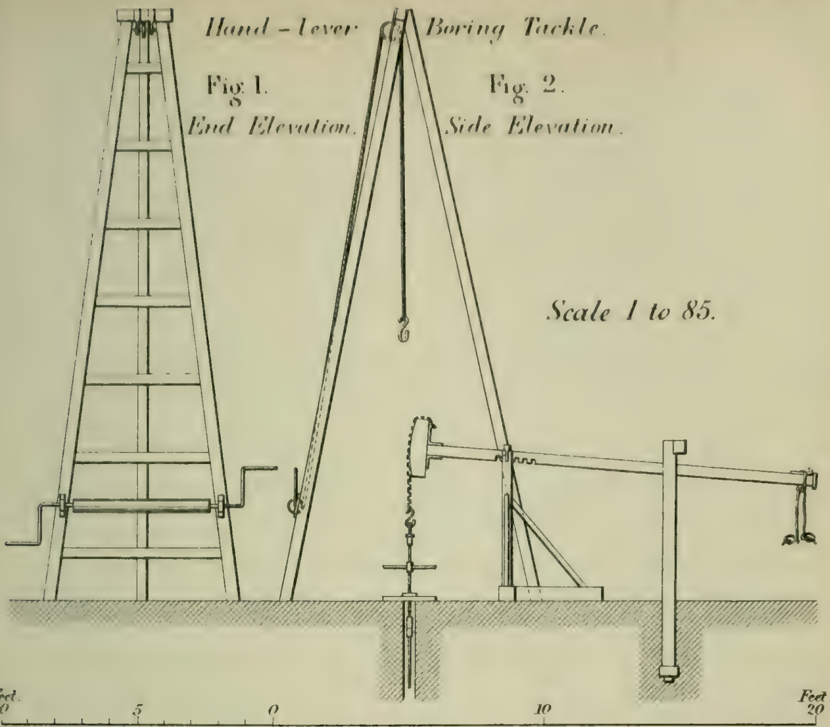
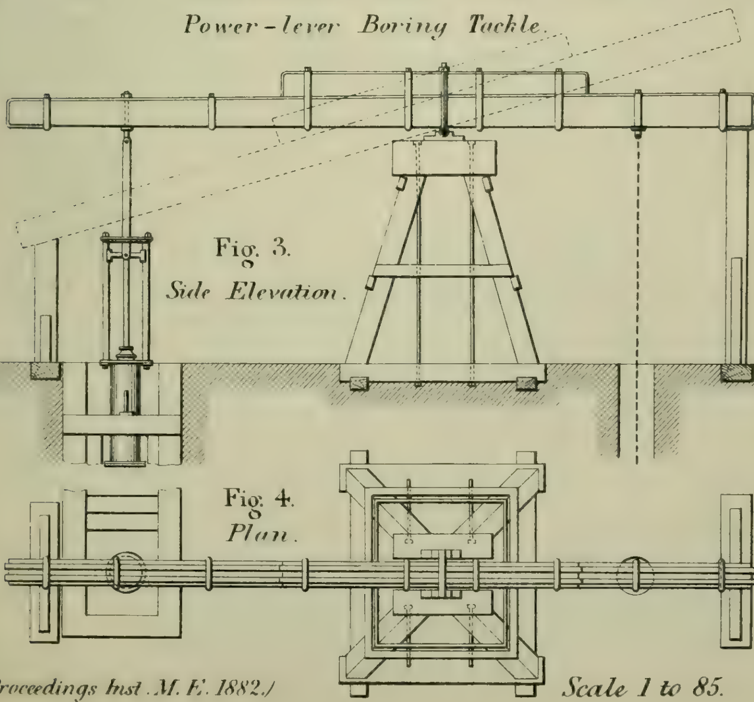


Fig. 8. *Gauge Tube with Stopper.*

(Proceedings Inst. M. E. 1882.)





(Proceedings Inst. M. E. 1882.) *Scale 1 to 85.*

Steam-winch Boring Tackle.

Fig. 5. *End Elevation.* Fig. 6. *Side Elevation.*

Scale 1 to 170.

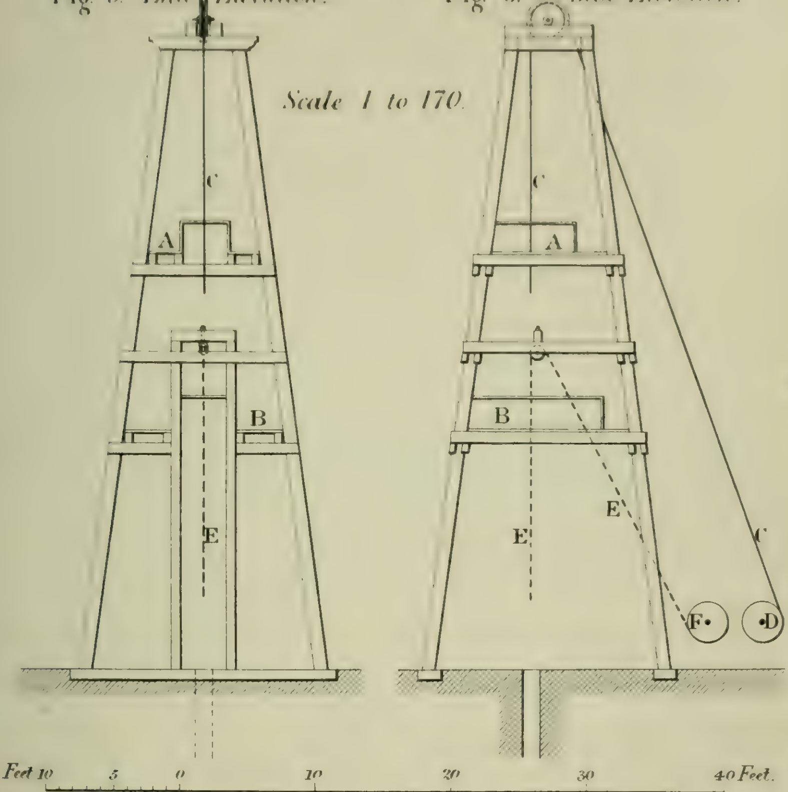
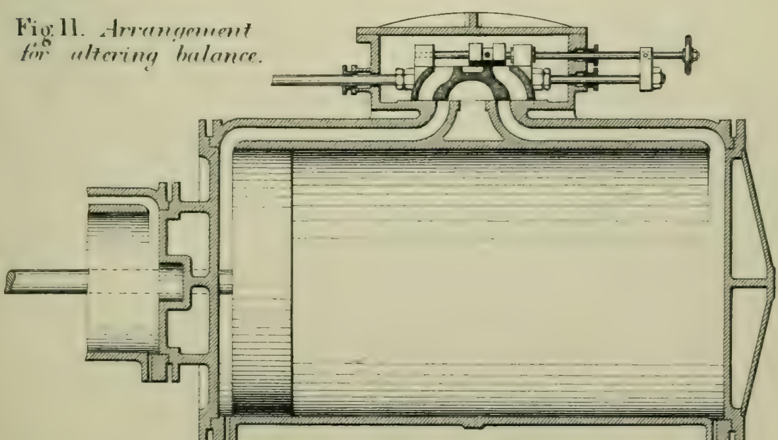


Fig. 11. *Arrangement for altering balance.*



Scale 1 to 32.

MINING MACHINERY.

Arrangements of Pumps during sinking.

Fig. 7.

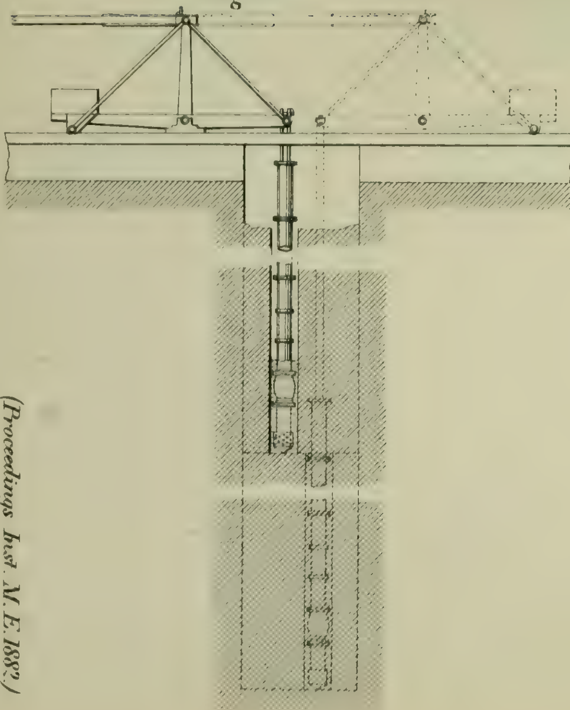


Fig. 8.

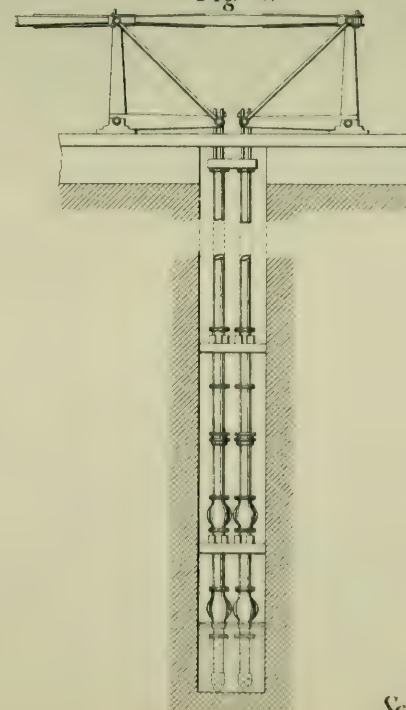
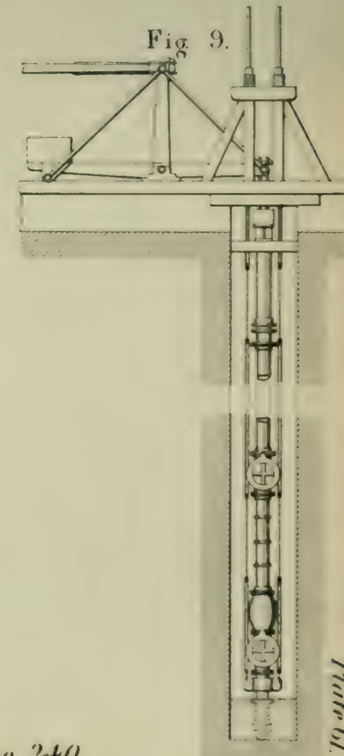


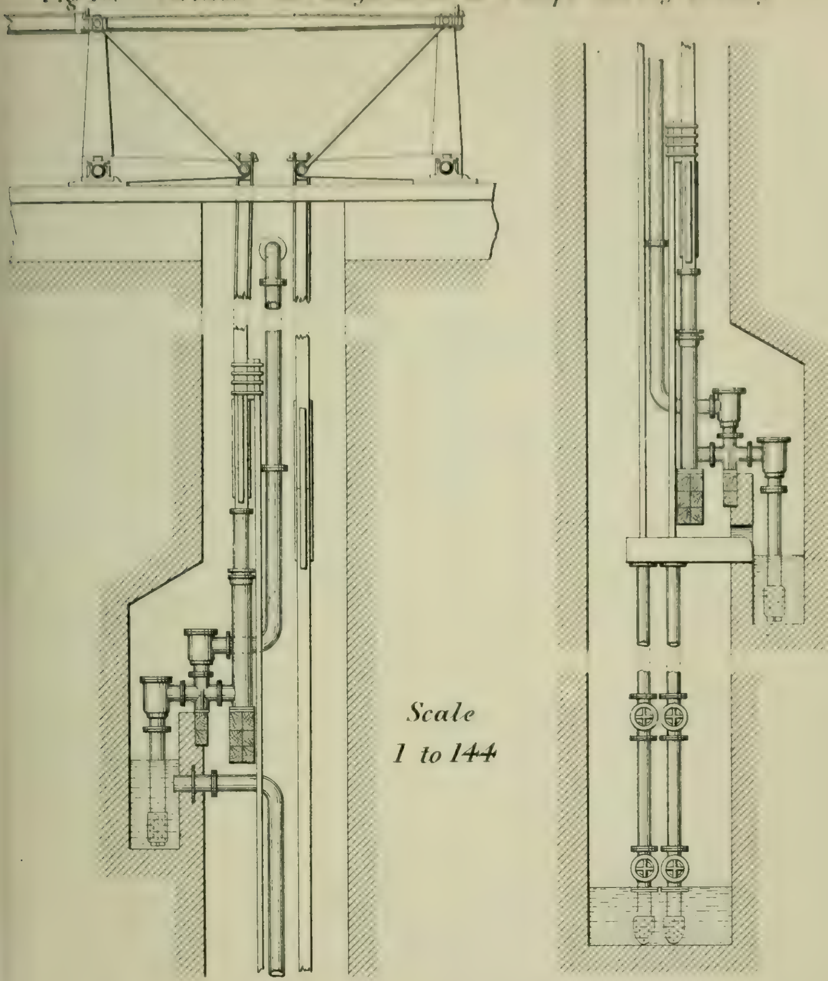
Fig. 9.



Scale 1 to 240.

Plate 61.

Fig 10. *Cornish arrangement of Pumps during sinking.*



Scale 1 to 144

Expansion Gear for direct-acting engines.

Fig. 15. *Side Elevation.*

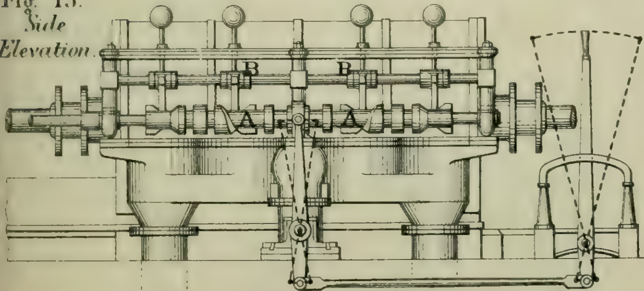
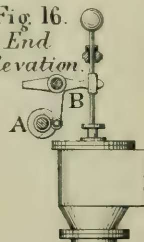


Fig. 16. *End Elevation.*



(Proceedings Inst. M.E. 1882.)

Scale 1 to 60

Retarding Gear for Pumping Engines.

Fig. 13.
Transverse Section.
at XX.

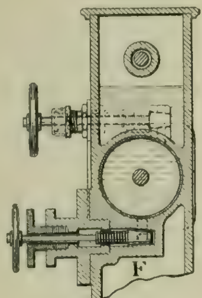


Fig. 12. *Longitudinal Section.*

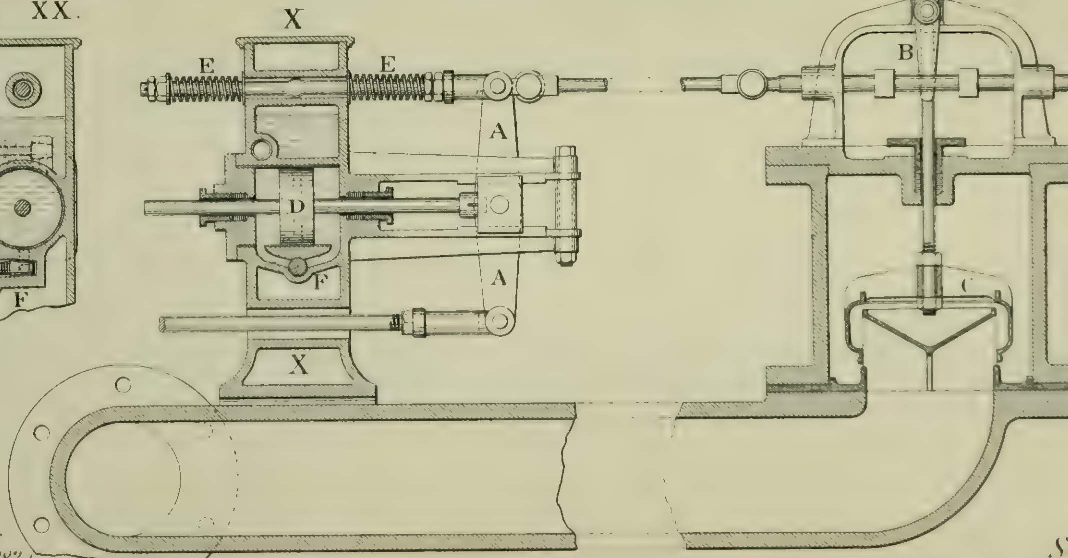
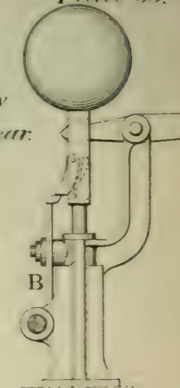


Fig 14.
End View
of Trip gear.



Scale 1 to 10

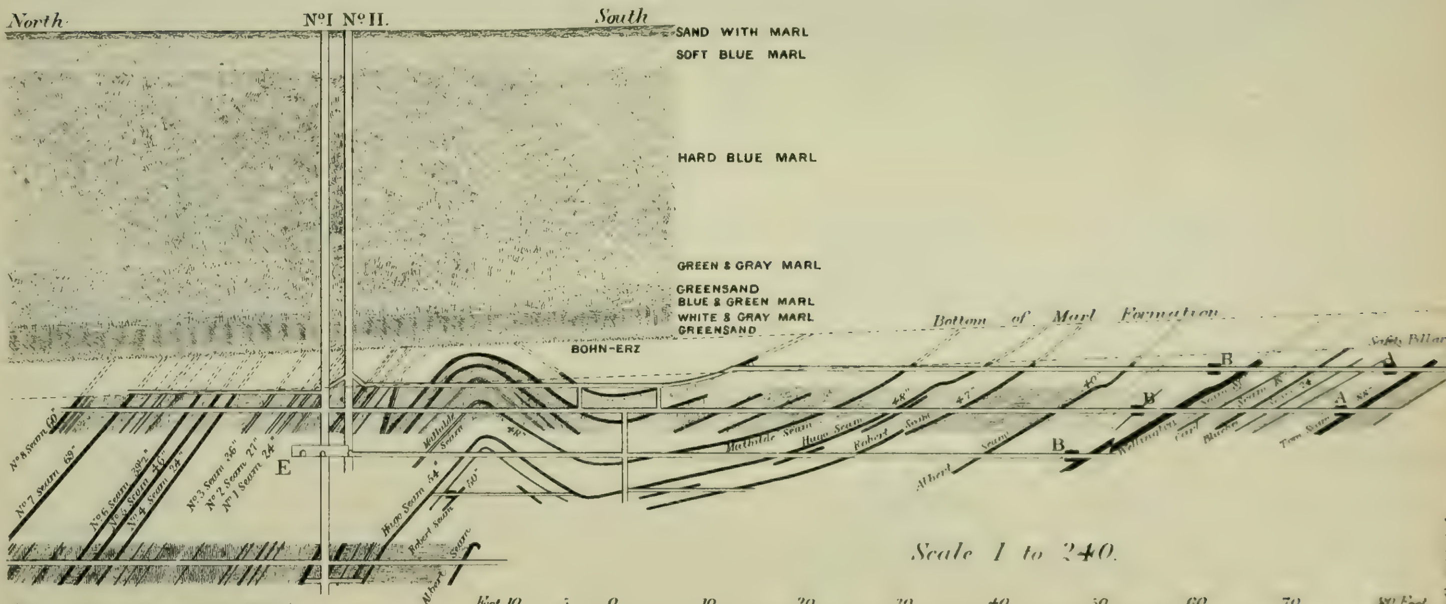
(Proceedings Inst. M. E. 1882.)

Plate 63.

MINING MACHINERY.

Erin Colliery, Westphalia.

Fig. 17. Section through Nos I and II Shafts.

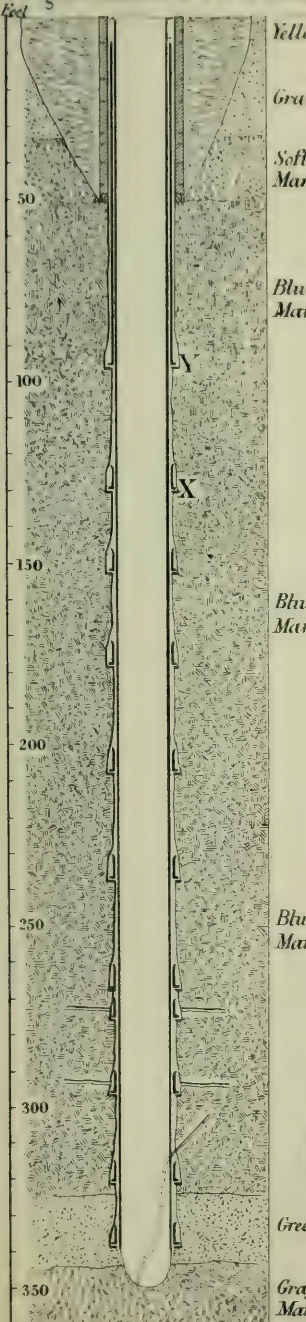


(Proceedings Inst. M.E. 1882.)

Plate 64.

Hansa Colliery

Fig. 18. *Section of N.° II Shaft.*



(Proceedings Inst. M.E. 1882.)

Details of Tubbing and Cribs.

Fig. 19. *Enlargement at X.*

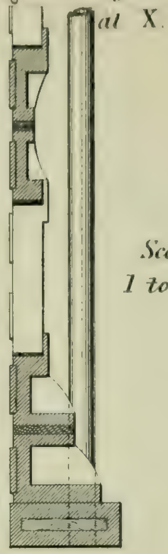


Fig. 20. *Enlargement at Y.*

Scale 1 to 32.

Brick-faced Tubbing.

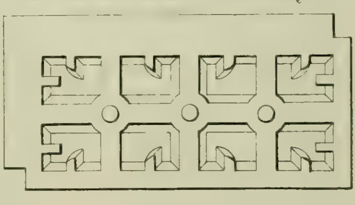


Fig. 21.

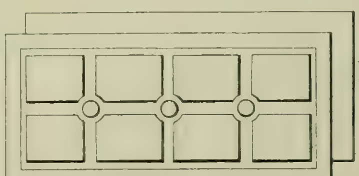


Fig. 22.

Wedging Crib.

Fig. 23.

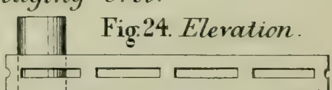


Fig. 24. *Elevation.*

Fig. 25. *Horizontal Section.*

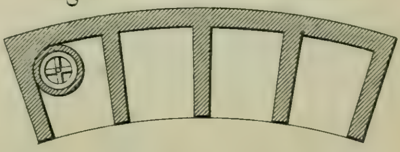
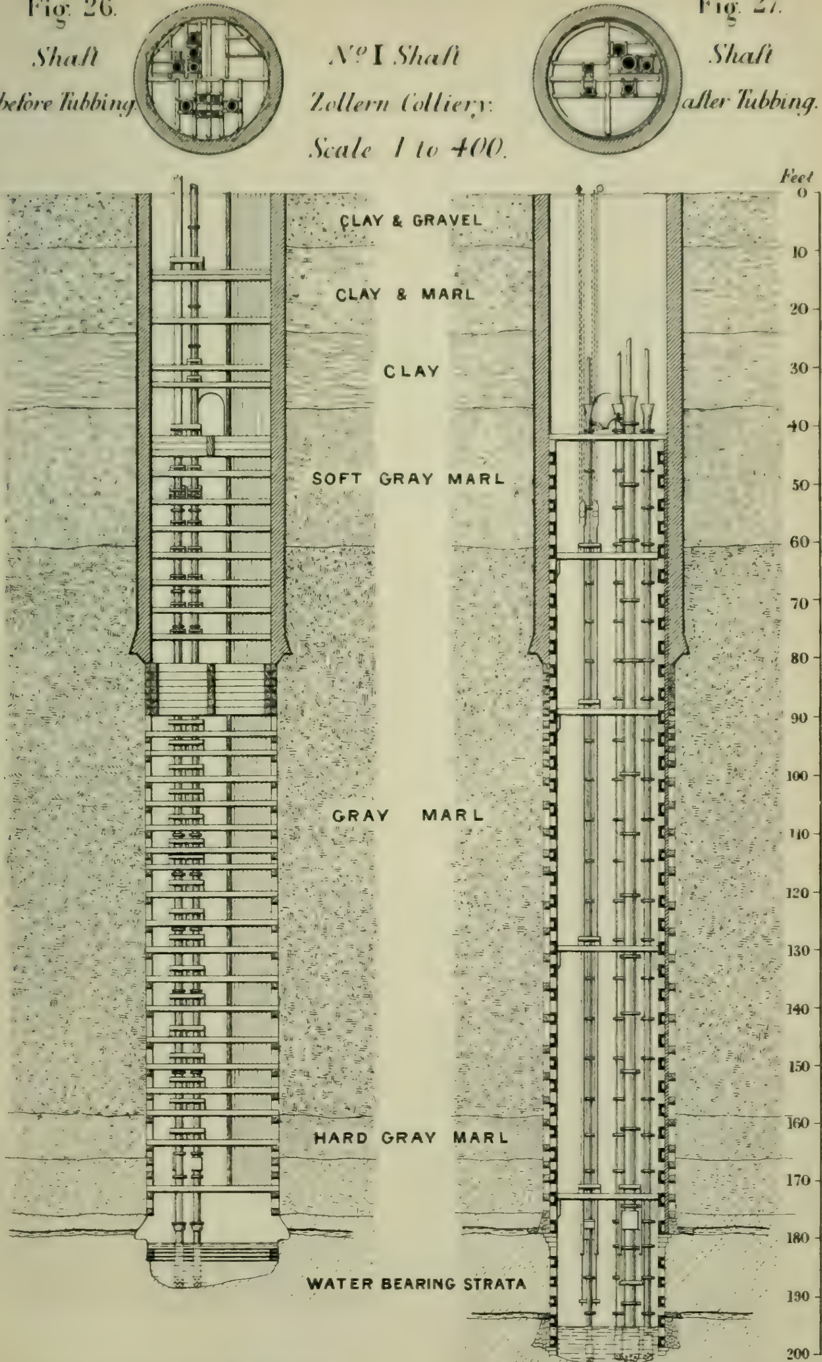


Fig. 26. *Shaft before Tubbing.*

No. I Shaft Zollern Colliery: Scale 1 to 400.

Fig. 27. *Shaft after Tubbing.*



(Proceedings Inst. M. E. 1882.)

No. I Shaft, Zollern Colliery.

Fig. 28. *Section showing Feeders 16th October 1868.*

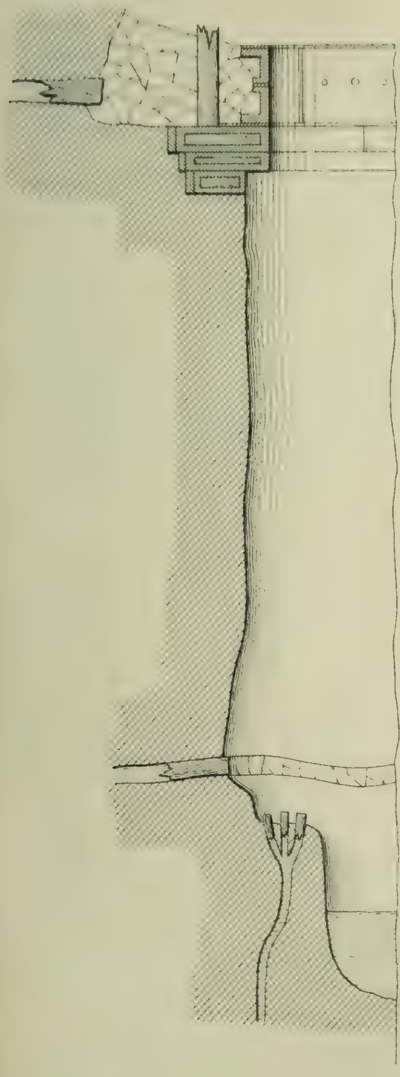


Fig. 29. *Section showing Tubbing 15th November 1868.*

Scale 1 to 50.

No II Shaft. Zollern Colliery.

Fig. 30. *Section of bottom, 4th July 1868.*

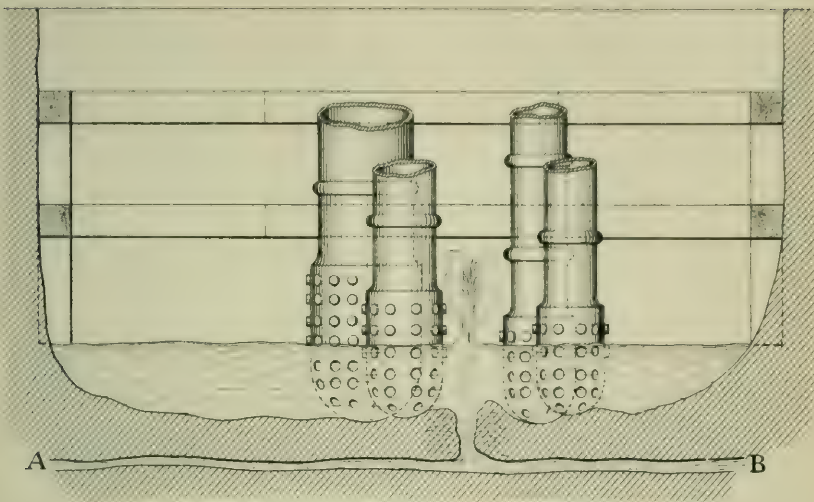
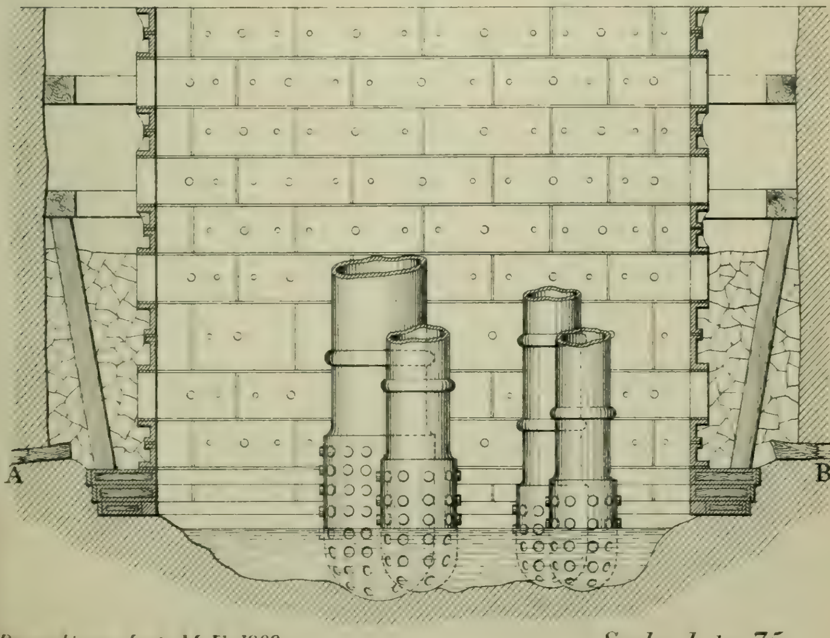


Fig. 31. *Section of bottom, 9th August 1868.*



 Scale 1 to 75.

MINING MACHINERY.

Steel Cages, Sandwell Park Colliery.

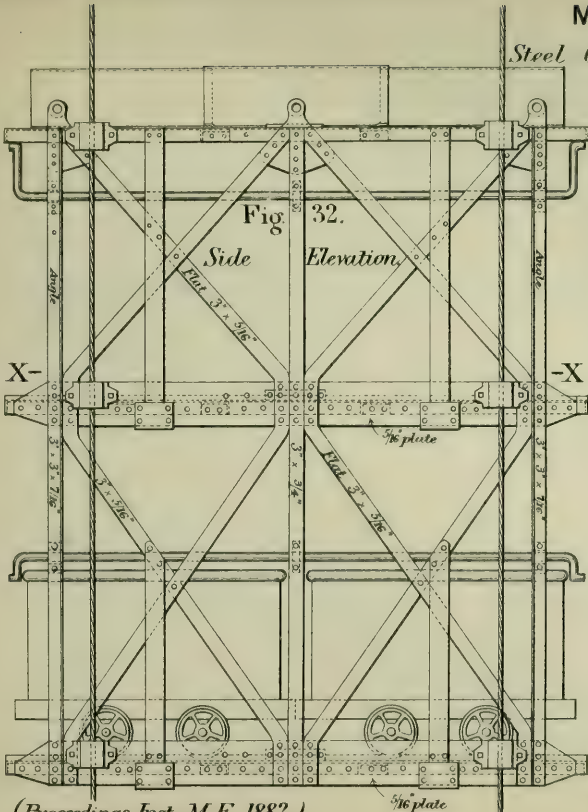


Fig. 32. *Side Elevation.*

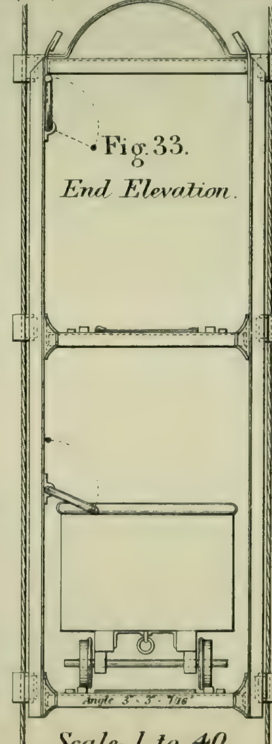


Fig. 33. *End Elevation.*

Fig. 34. *Horizontal Section at XX Fig. 32.*

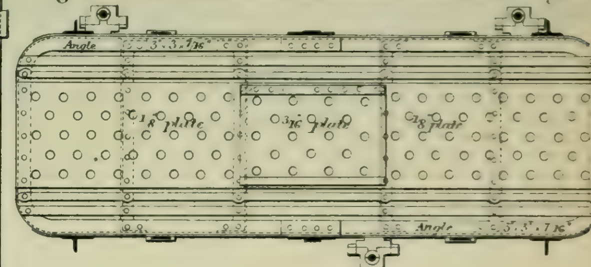
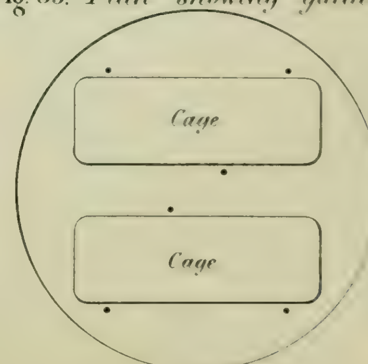


Fig. 35. *Plan showing guide-ropes.*

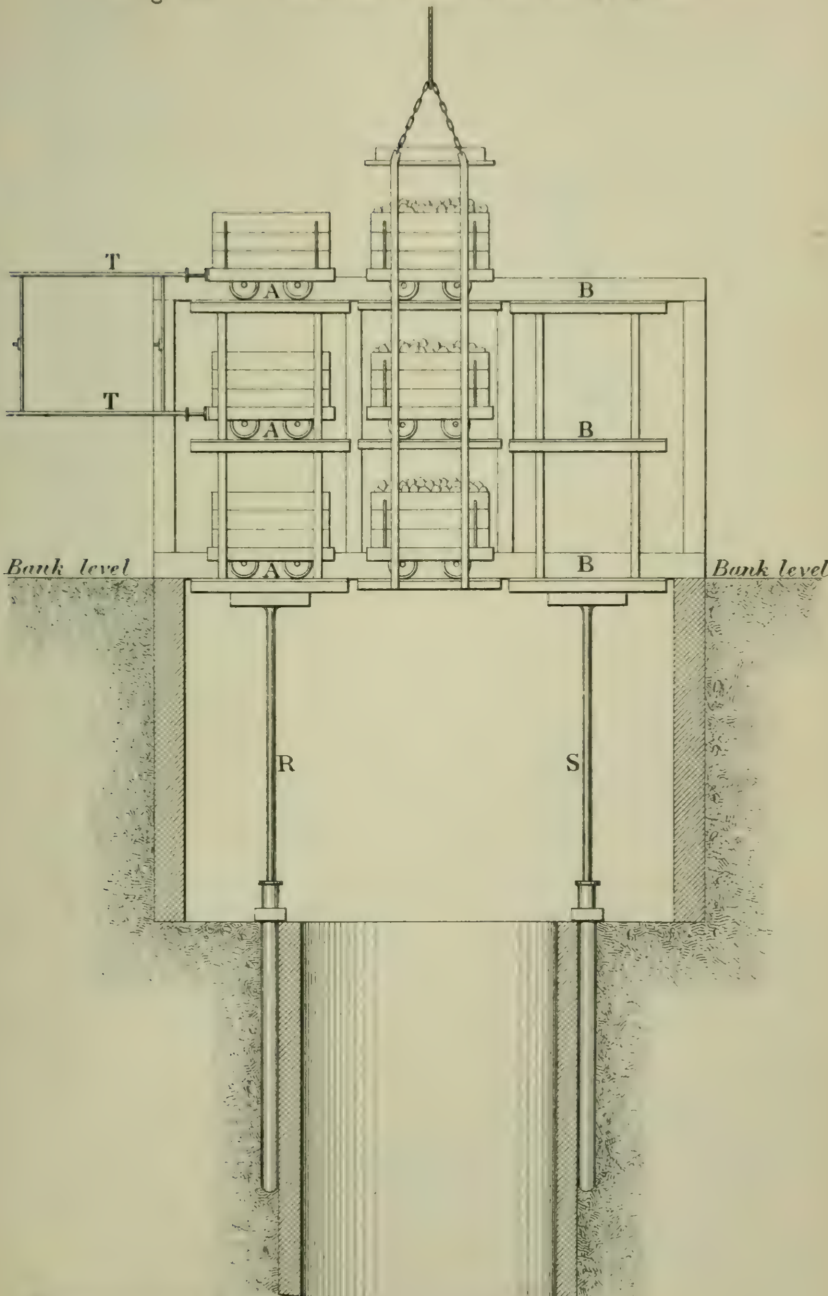


(Proceedings Inst. M.E. 1882.)

Scale 1 to 40.

Plate 69.

Fig. 36. *Fowler's Tub-shifting gear.*



(Proceedings Inst. M.E. 1882.)

TESTING MACHINE.

Fig. 1. *General Elevation.*

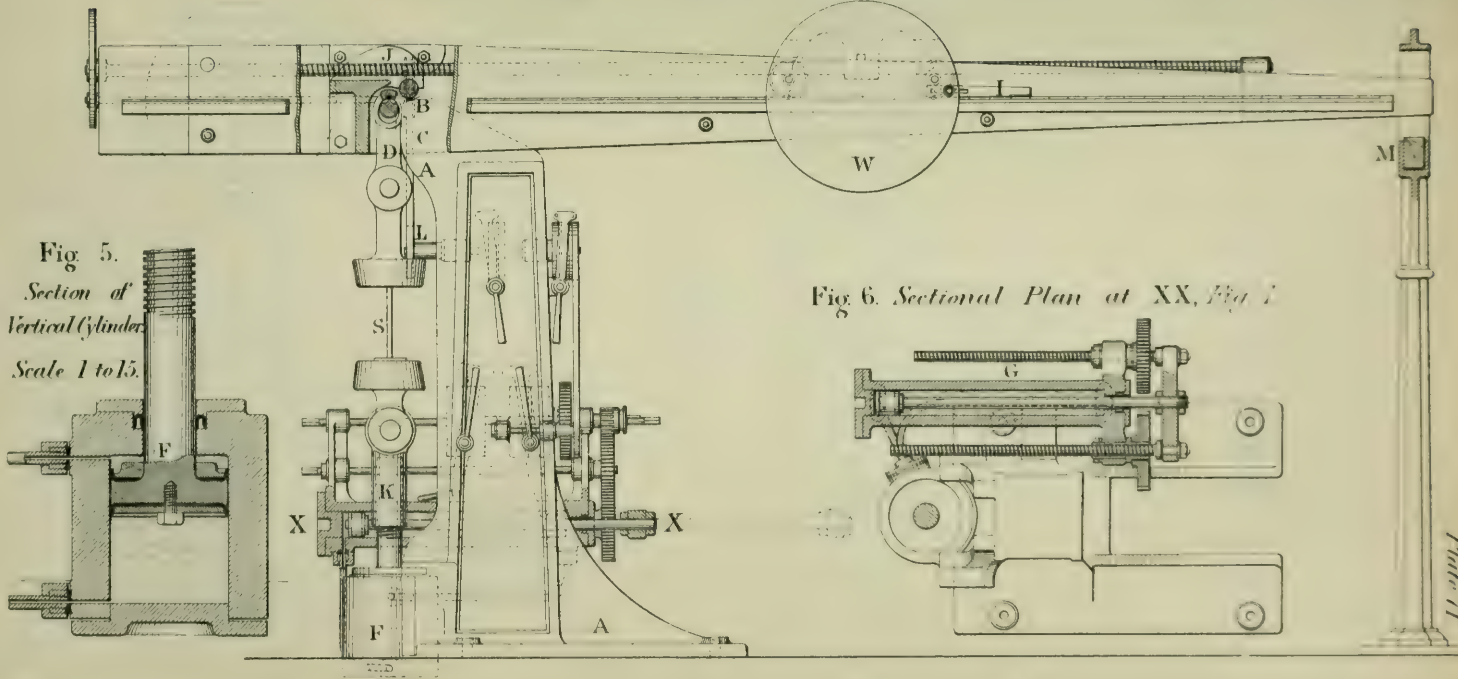


Fig. 5. *Section of Vertical Cylinder. Scale 1 to 15.*

Fig. 6. *Sectional Plan at XX, Fig. 1.*

Scale 1 to 30.

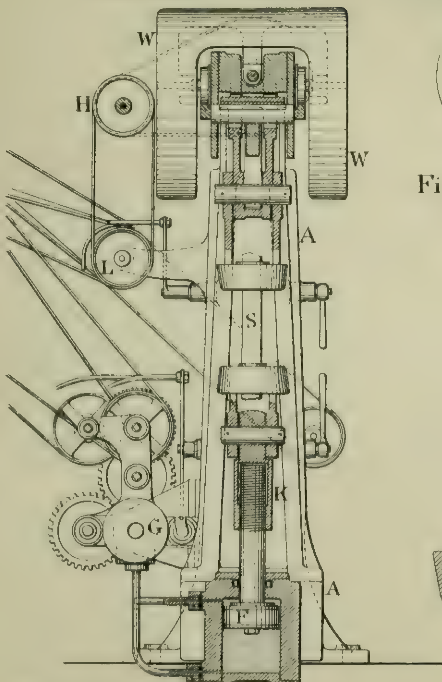
(Proceedings Inst. M. E. 1882.)

Plate 71.

TESTING MACHINE.

Fig. 2.

Transverse Section.



Clip Box.

Fig. 3. *Plan.*

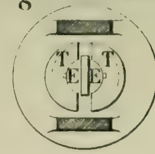
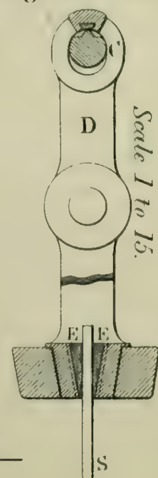


Fig. 4. *Section.*



Scale 1 to 15.

Bending Apparatus.

Fig. 8. *End Elevation.*

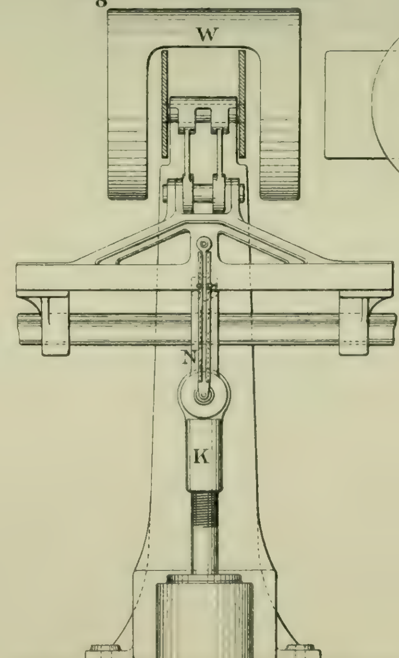
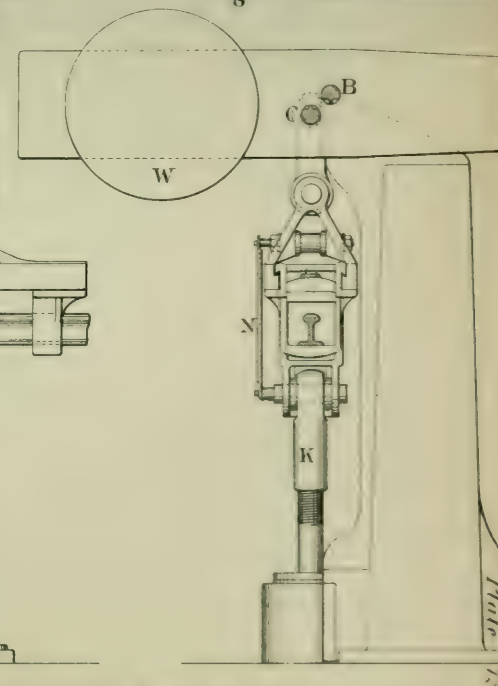


Fig. 9. *Side Elevation.*



(Proceedings Inst. M.E. 1882.)

Scale 1 to 30.

TESTING MACHINE.

Compression apparatus.

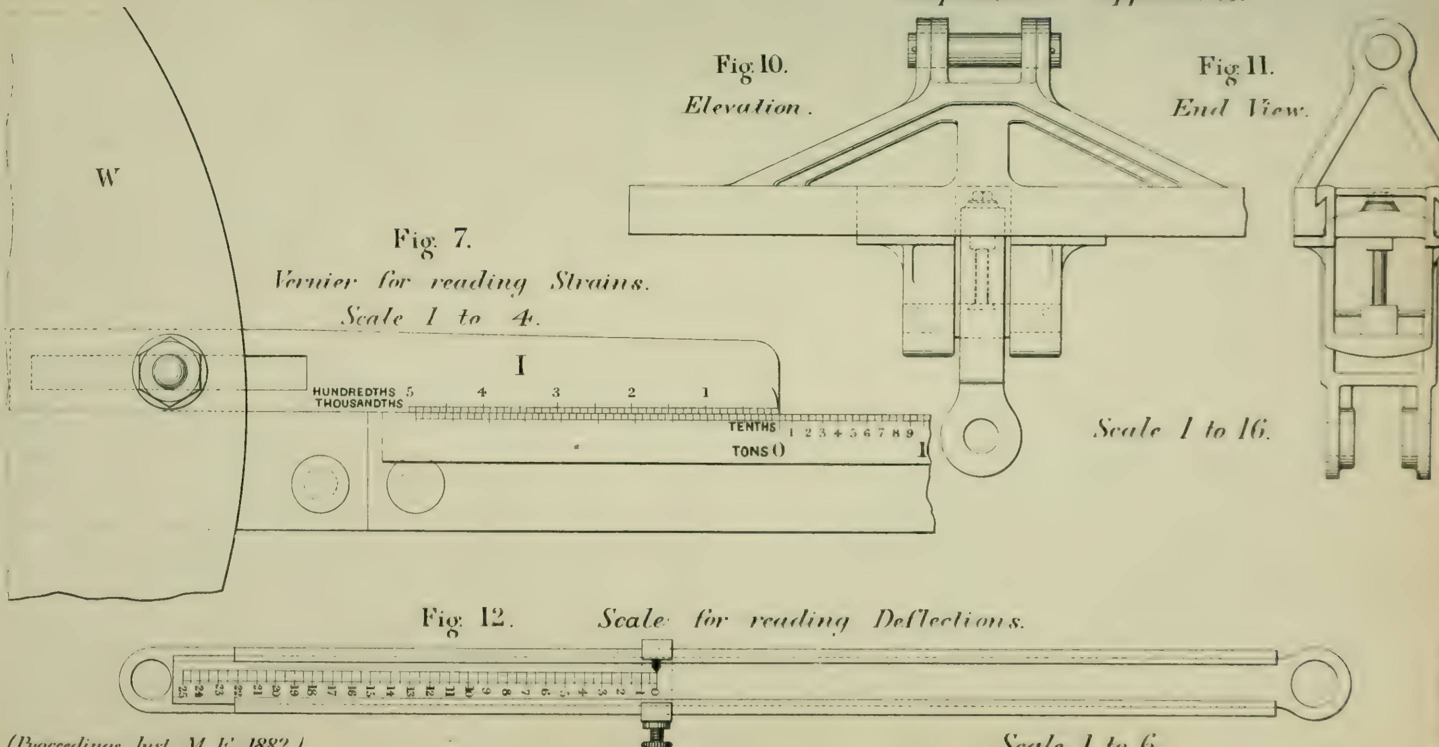


Fig. 7.
Vernier for reading Strains.
Scale 1 to 4.

Fig. 10.
Elevation.

Fig. 11.
End View.

Scale 1 to 16.

Fig. 12. *Scale for reading Deflections.*

Scale 1 to 6.

(Proceedings Inst. M. E. 1882.)

Plate 73.

AUTOMATIC EXPANSION.

Assumed Indicator Diagrams.

Fig. 1. *Single Valve.*

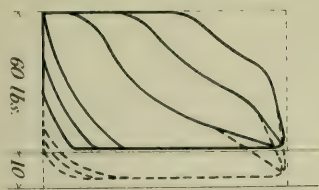


Fig. 2. *Double Valve.*

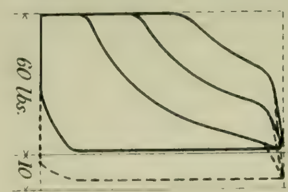


Fig. 3. *Throttling*

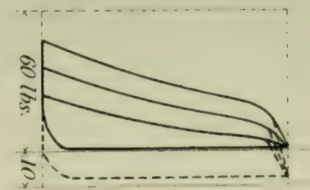


Fig. 4.

1 *Line for Diagram Fig. 1 condensing.*
1a " " " " *non-condensing.*
2 " " *Fig. 2 condensing.*
2a " " " *non-condensing.*

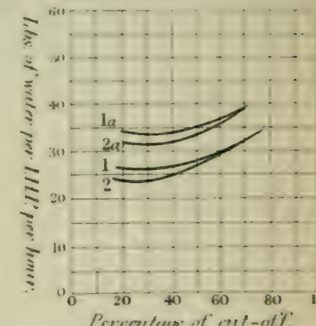
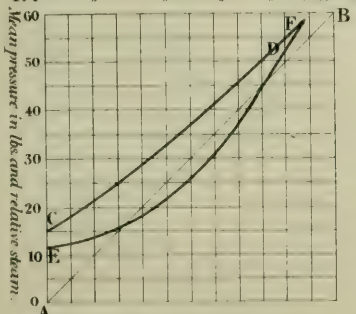


Fig. 5.

A B *Mean Pressure on piston in lbs.*
C D *Relative Steam used with throttling.*
E F " " " " *automatic expansion*



(Proceedings Inst. M. E. 1882.)

Fig. 6. *Curves of Relative Steam used, with expansion or throttling, for variable load*

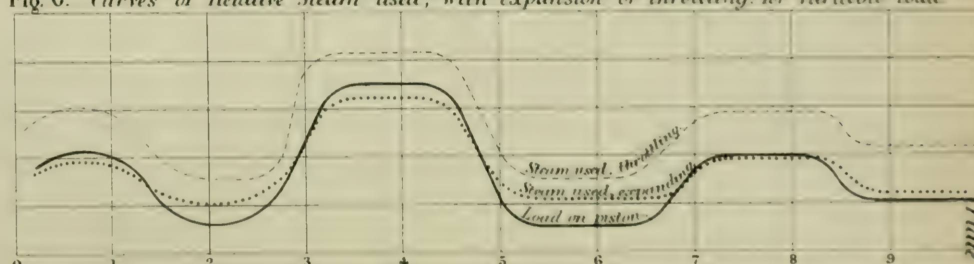


Plate 74

AUTOMATIC EXPANSION.

Fig. 7. *Perfect Governing.*

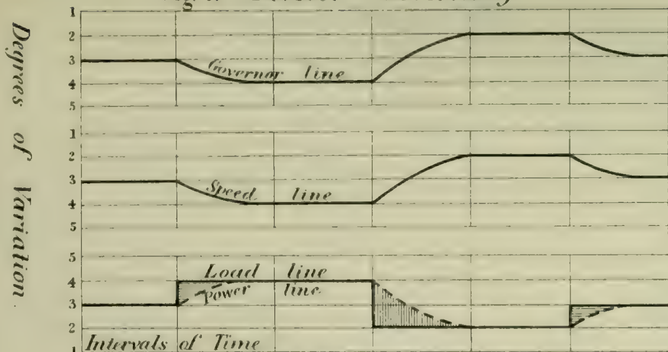


Fig. 8. *Retardation from Storage.*

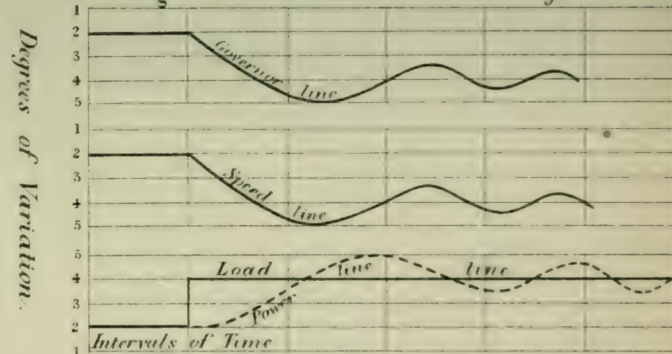


Fig. 11. *Retardation from Friction.*

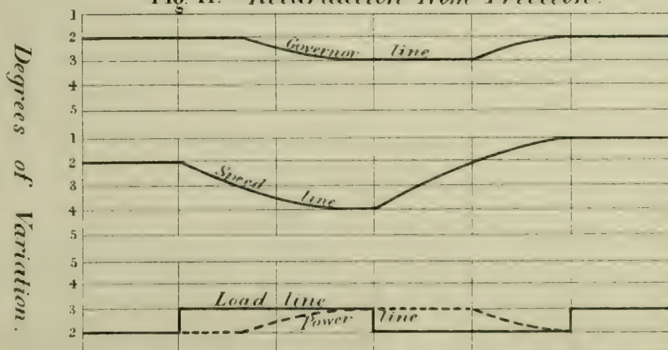
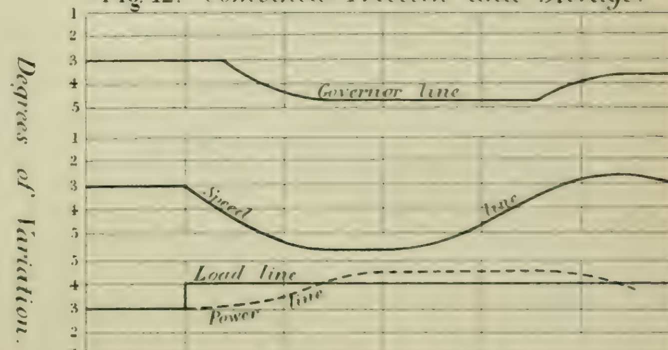


Fig. 12. *Combined Friction and Storage.*



Intervals of Time. *Intervals of Time.*

(Proceedings Inst. M.E. 1882.)

Plate 75.

AUTOMATIC EXPANSION.

Fig. 9.

8 H.P. Governor,

Revs. 57 to 63.

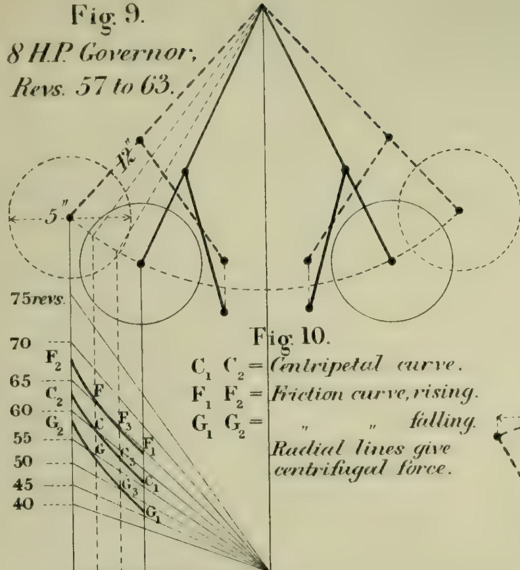


Fig. 10.

C_1 C_2 = *Centripetal curve.*

F_1 F_2 = *Friction curve, rising.*

G_1 G_2 = " " *falling.*

Radial lines give centrifugal force.

Automatic Expansion Regulators.

Fig. 25.

For 8 H.P. engine.

Revs. 280 mean.

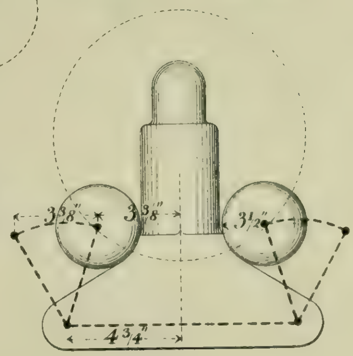
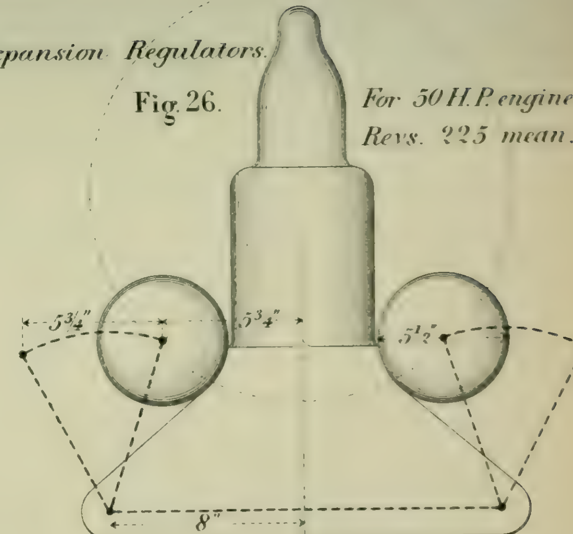


Fig. 26.

For 50 H.P. engine.

Revs. 225 mean.



Sections of Cut-off Valves.

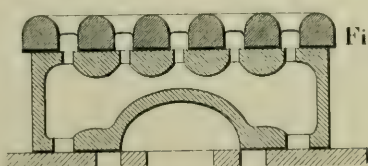


Fig. 16.

(Proceedings Inst. M.E. 1882.)

Fig. 17.

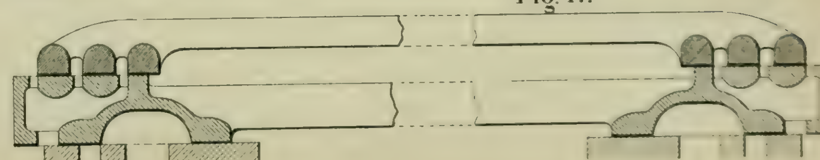


Plate 76.

AUTOMATIC EXPANSION.

Fig. 15.
Valve Resistances.

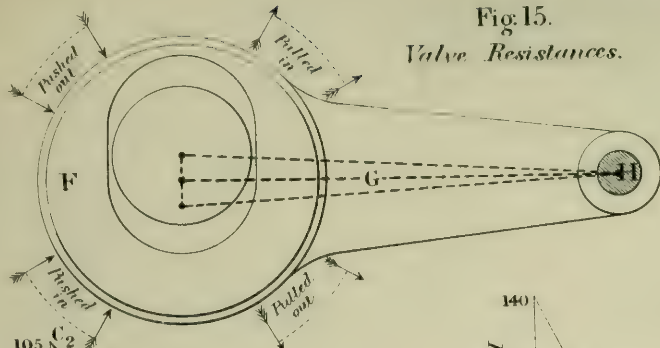
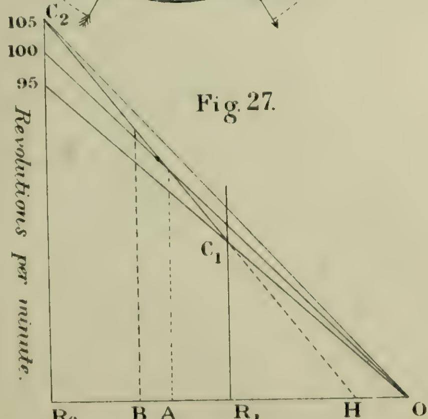


Fig. 27.



(Proceedings Inst. M. E. 1882.)

Fig. 28. *Effect of screwing up Springs.*

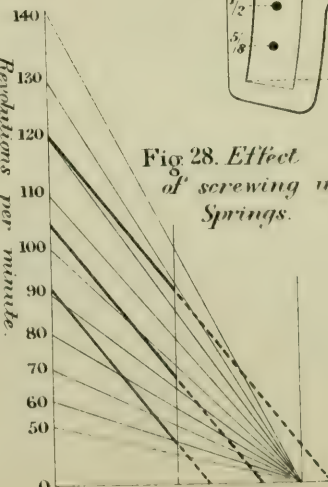


Fig. 31. *Cut-off varied by Link-block.*

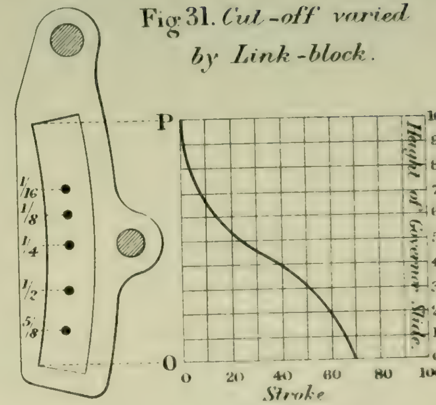


Fig. 32.

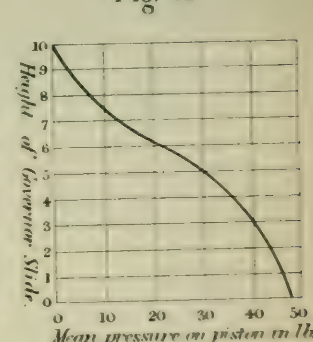


Fig. 29. *Variation 2% from mean.*

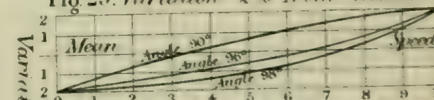


Fig. 30. *Variation 4% from mean.*

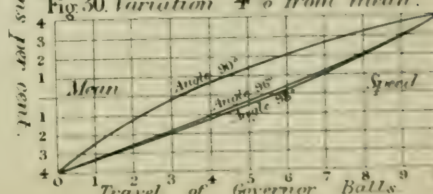


Plate 77.

AUTOMATIC EXPANSION.

Governor for separate cut-off valve.

Fig. 13. *Elevation.*

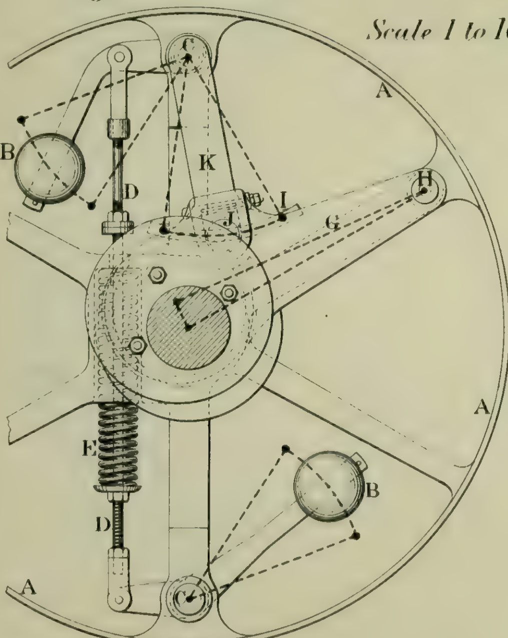
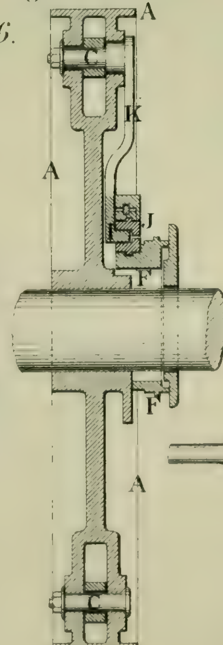


Fig. 14. *Section.*

Scale 1 to 16.



Automatic Expansion Regulator.

Fig. 22. *Elevation.*

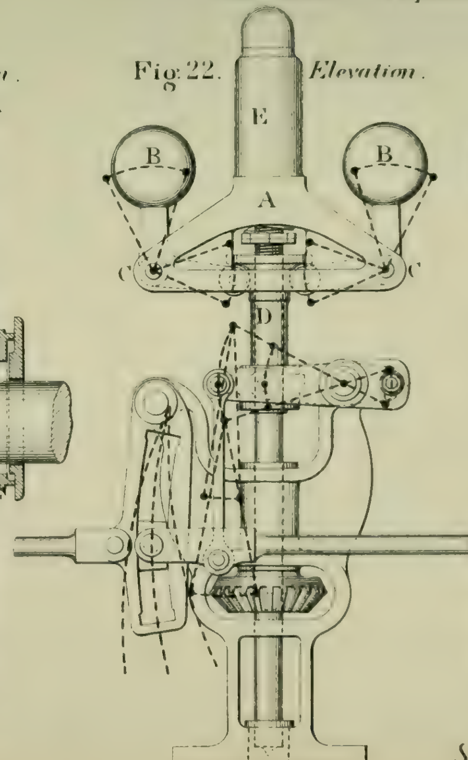


Fig. 23. *Section.*

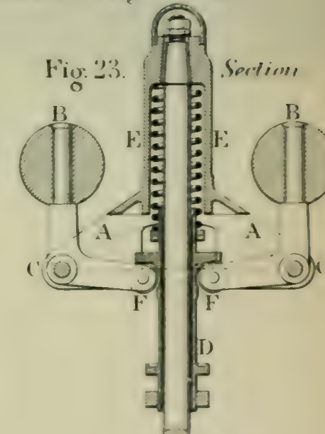
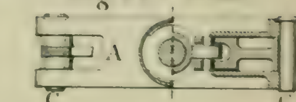


Fig. 24. *Plan.*



Scale 1 to 8.

(Proceedings Inst. M. E. 1882.)

Plate 78.

Governor applied to single slide-valve.

Fig. 18. *Elevation, in action.*

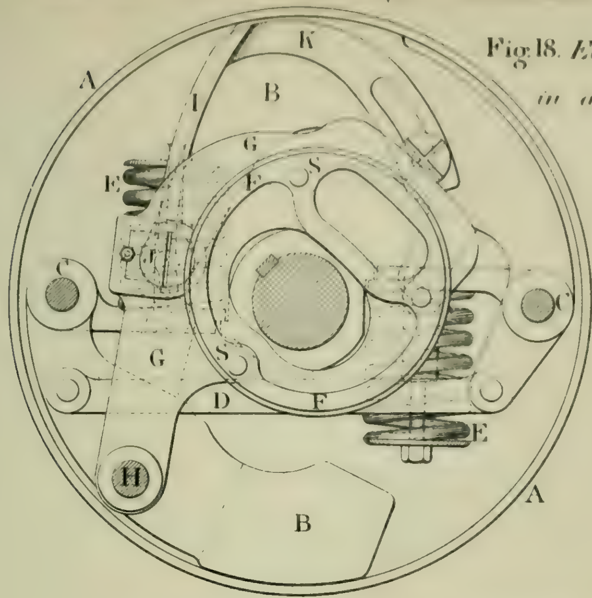


Fig. 19. *Elevation, at rest.*

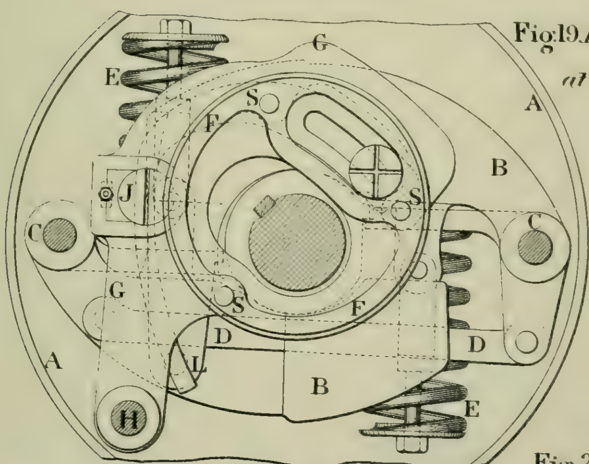
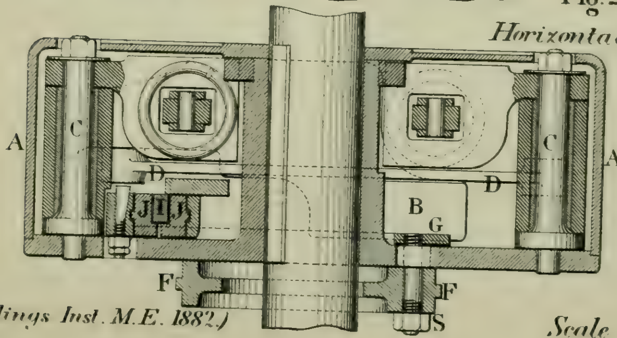


Fig. 20. *Horizontal Section.*



Scale 1 to 6.

Simpler form of Single-slide Governor.

Fig. 21. *Elevation, in action*

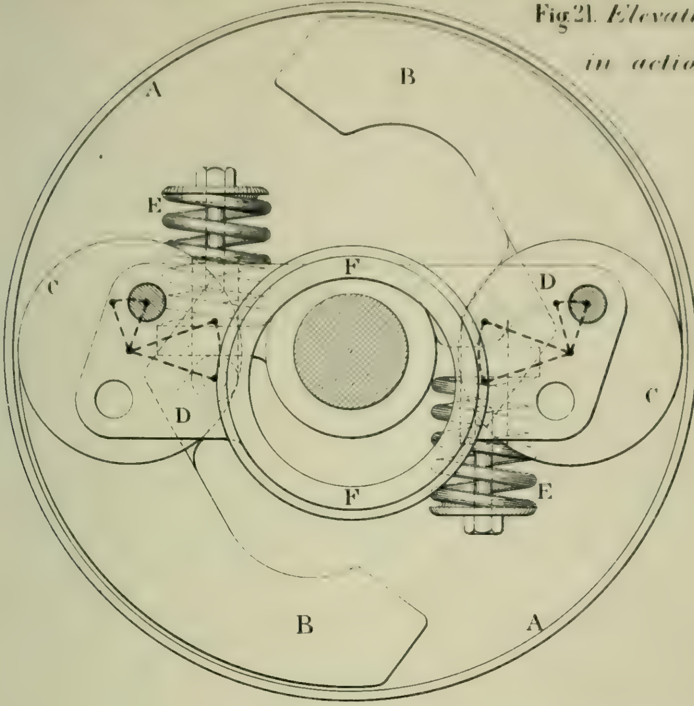
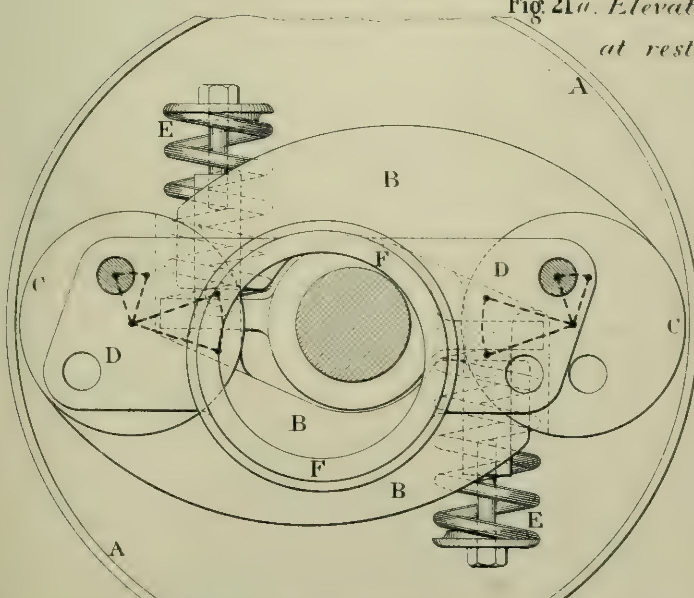


Fig. 21*a*. *Elevation, at rest.*



Scale 1 to 5.

Indicator Diagrams.

Fig. 33. *With Governor working single slide-valve.*

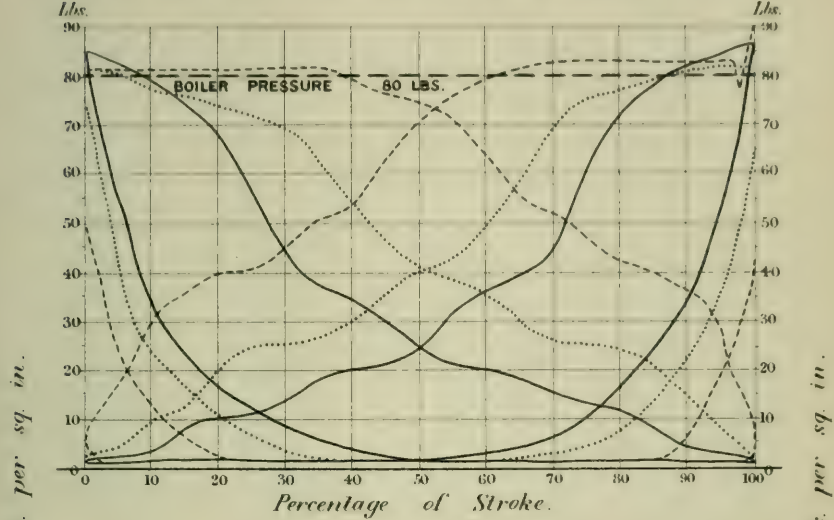
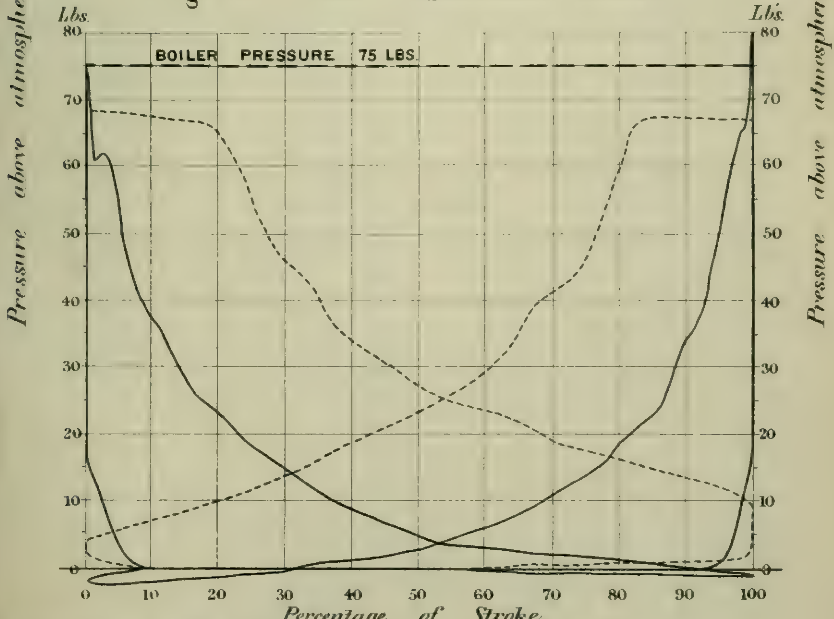


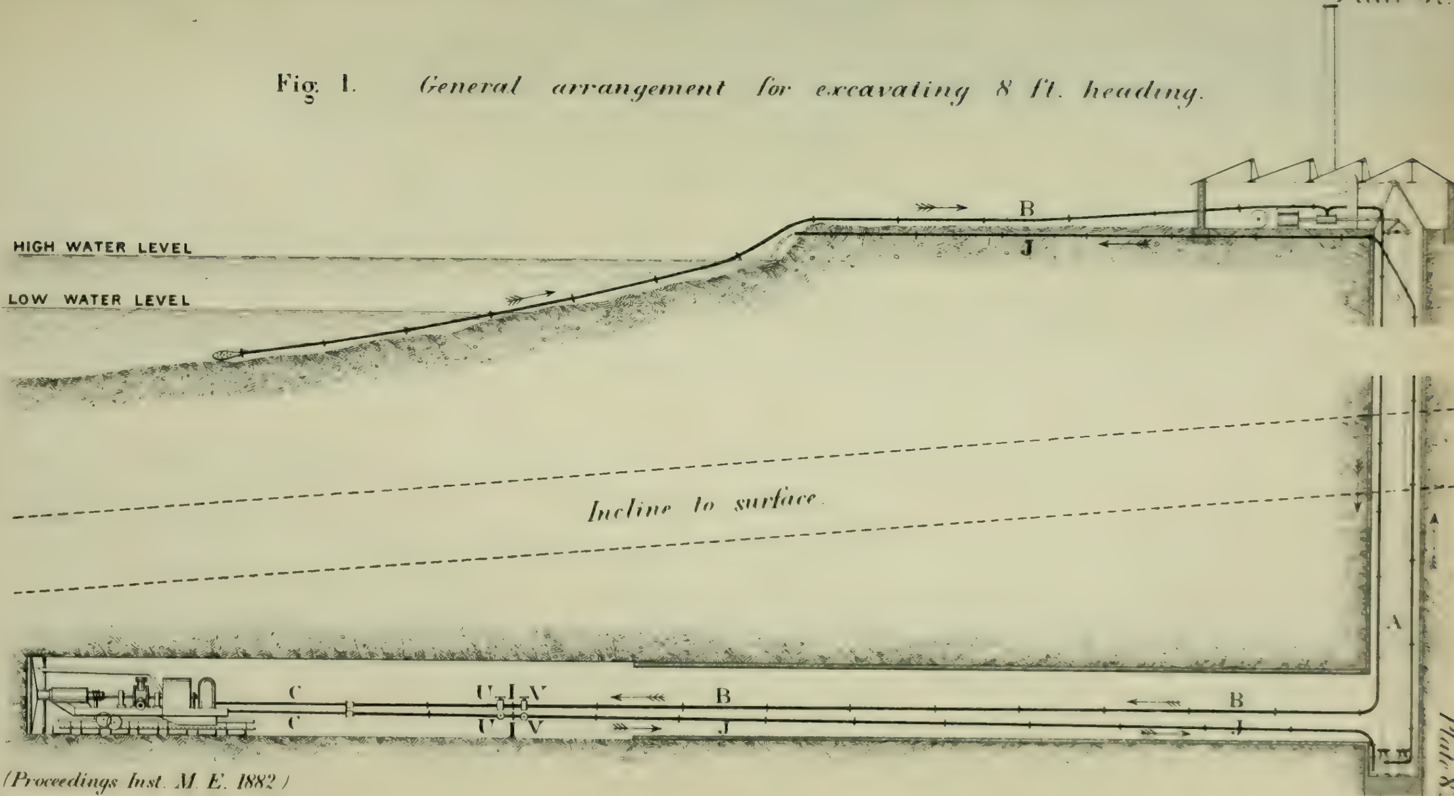
Fig. 34. *With Expansion Valve.*



(Proceedings Inst. M.E. 1882.)

CHANNEL TUNNEL.

Fig. 1. *General arrangement for excavating 8 ft. heading.*



(*Proceedings Inst. M. E. 1882.*)

Plate 82.

CHANNEL TUNNEL.

Fig. 2. *Elevation of Excavator for 8 ft. heading.*

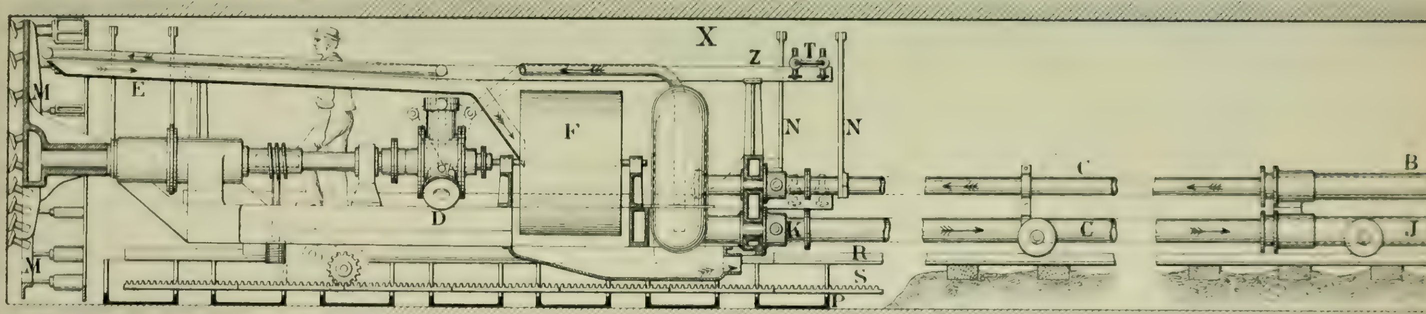
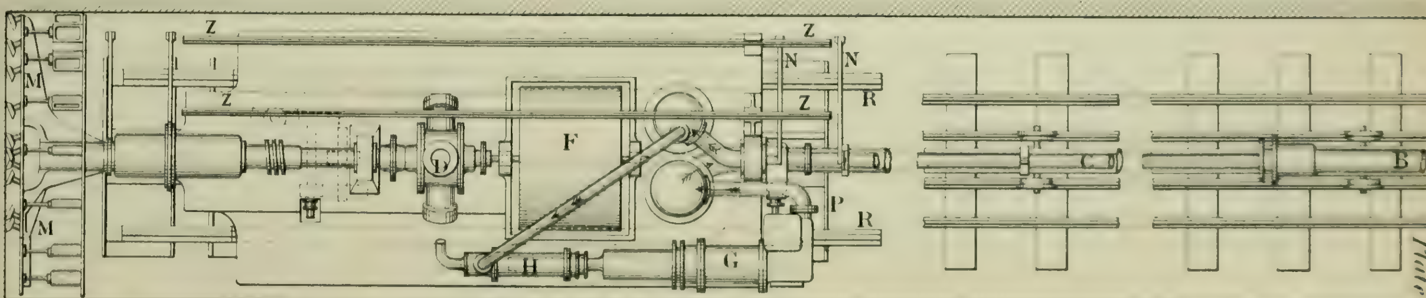


Fig. 3. *Plan.*



 Scale 1 to 64.

0 5 10 15 20 Feet

Plate 83.

CHANNEL TUNNEL.

Fig. 4. *End Elevation of Boring Head, looking backwards. 8 ft. heading.*

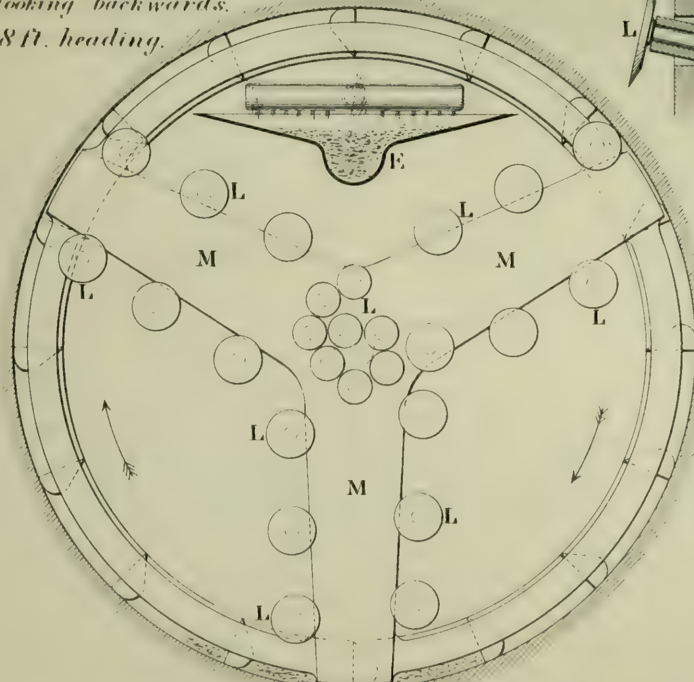


Fig. 6.

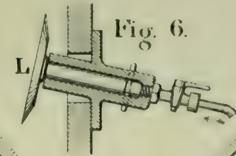
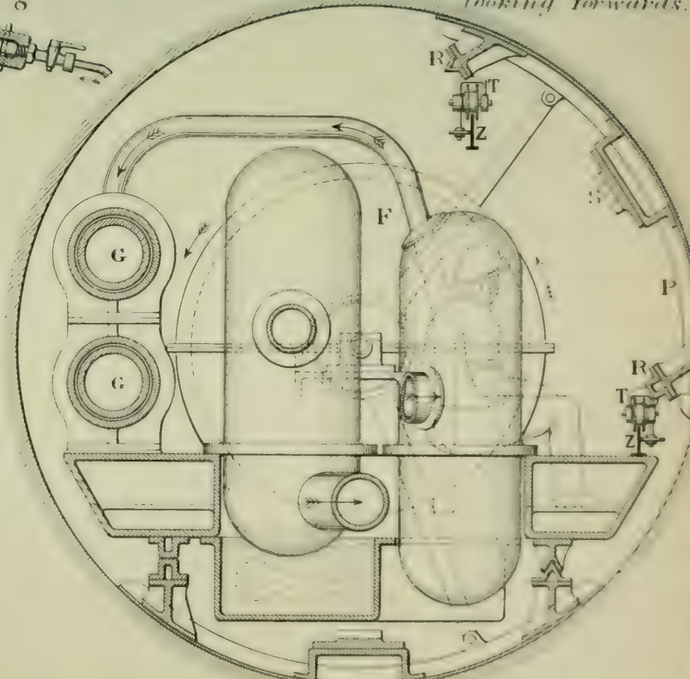


Fig. 5. *Section at XX, Fig. 2, looking forwards.*



Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet

(Proceedings Inst. M.E. 1882.)

Institution of Mechanical Engineers.

PROCEEDINGS.

November 1882.

The Autumn Meeting of the Institution was held in the Memorial Hall, Albert Square, Manchester, on Friday, 3rd November, 1882, at Three p.m.; Percy G. B. Westmacott, Esq., President, in the chair, succeeded by John Ramsbottom, Esq., Past-President.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and the following candidates had been found to be duly elected :—

MEMBERS.

William Milward Allen,	Manchester.
William Cross,	Newcastle-on-Tyne.
William Douglas Cruickshank,	Sydney.
William Fox,	Leeds.
Edward Wyburd Furrell,	London.
Charles Randolph Harvey,	Glasgow.
Reuben Hunt,	Castleford.
John Jardine,	Nottingham.
Samuel Gilbert Jones,	Rangoon.
Walter Lord,	Todmorden.
Henry Cripps Matheson,	Nottingham.
Walter Martin Musgrave,	Bolton.
Edward McKillop Nicholl,	Amritsar.
John Thomas North,	Iquique.
Harry Olrick,	London.
James Orange,	Hong Kong.

Alfred Perry, ...	Spon Lane.
George Richards, ...	Manchester.
Albert Edward Seaton, ...	Hull.
John Swaine, ...	Glasgow.
Stephen Harding Terry, ...	London.
Thomas Turner, ...	Manchester.

ASSOCIATES.

William Jackson, ...	Hull.
Alexander James Wallis Tayler, .	London.

GRADUATE.

Edward Wingfield Bowles, . . .	London.

The President announced that the President, two Vice-Presidents, and five Members of the Council, would go out of office at the ensuing Annual General Meeting, according to the Rules of the Institution; and that the list of those retiring was as follows:—

PRESIDENT.

Percy G. B. Westmacott, ...	Newcastle-on-Tyne.

VICE-PRESIDENTS.

Jeremiah Head, ...	Middlesbrough.
Charles P. Stewart (*deceased*), . .	Sunninghill.

MEMBERS OF COUNCIL.

Daniel Adamson, ...	Manchester.
J. Hawthorn Kitson, ...	Leeds.
William Menelaus (*deceased*), . .	Dowlais.
Joseph Tomlinson, Jun., ...	London.
R. Price Williams, ...	London.

Of the Retiring names the following were nominated by the Council for re-election:—

PRESIDENT.

Percy G. B. Westmacott, ... Newcastle-on-Tyne.

VICE-PRESIDENT.

Jeremiah Head, ... Middlesbrough.

MEMBERS OF COUNCIL.

Daniel Adamson, ... Manchester.
J. Hawthorn Kitson, ... Leeds.
Joseph Tomlinson, Jun., ... London.
R. Price Williams, ... London.

The following additional candidates were also nominated by the Council for election at the Annual General Meeting:—

Election as Member.

VICE-PRESIDENT.

1847. Thomas R. Crampton, ... London.

MEMBERS OF COUNCIL.

1859. Edward Bindon Marten, . . . Stourbridge.
1865. Bernhard Samuelson, M.P., F.R.S., London.
1867. Ralph H. Tweddell, ... London.
1881. Edward Pritchard Martin, . . Dowlais.
1882. William Denny, F.R.S.E., . . . Dumbarton.

According to the Rules of the Institution, it was now open to any Member to add to the list of candidates.

No addition was made to the list.

The President reminded the Meeting that, if any Member had any motion to propose at the Annual General Meeting, in reference to the Bye-Laws, notice must be given of it at the present meeting.

No such notice was given.

The following papers were then read and discussed:—

On the Fromentin Automatic Boiler Feeder; by Mr. John Hayes, of London.

On the Automatic Screw-Brake; by Mr. W. Parker Smith, of London.

On a Centrifugal Separator for Liquids of different specific gravities; by Mr. Waldemar Bergh, of London.

On the motion of the Chairman, votes of thanks were severally passed to the authors for their valuable papers.

The Meeting then terminated.

ON THE FROMENTIN AUTOMATIC BOILER FEEDER.

By Mr. JOHN HAYES, of London.

The application of automatic means to the feeding of steam boilers is looked upon by many engineers as somewhat dangerous and unreliable. But the illusory nature of the doubts entertained, and the practicability of successfully employing a self-acting feeder, are established, in the author's opinion, by the experience of the Automatic Boiler Feeder for stationary boilers, invented by M. Edouard Fromentin, of Paris, which forms the subject of the present paper. This apparatus has been working in London since December 1881 under the author's supervision, and in Paris for a considerably longer period under the direction of the inventor.

All who have to do with the working of steam boilers are aware that the present system of feeding by means of pumps, injectors, and similar appliances, is attended with great disadvantages in regard not only to safety, but also to economy in working and in repairs. Notwithstanding the utmost care and attention, far too wide a latitude has of necessity to be allowed in the conditions under which a boiler may be worked. In general the attendant is not merely responsible for keeping the water at its proper level, but has also the firing to do, and not unfrequently the engines to look after, machinery to oil, and sundry other work to perform. Hence it occurs that boilers do very often get neglected in working; sometimes the water-level rises too high, but oftener falls too low; and the evil is only discovered just in the nick of time. When so discovered, much injury results to the over-heated plates from the sudden influx of a large supply of cold water, through the feed being turned on full bore. Severe

strains are produced through the sudden contraction thus occasioned, and actual explosions are no doubt occasionally due to this cause. By proper automatic feeding such evils are rendered impossible. The failure of previous attempts to produce a successful automatic feeder has arisen chiefly from the apparatus being too complex, and hampered with a variety of working parts, such as floats and valves, which have been liable through unexpected irregularities to cease acting.

The Fromentin Automatic Boiler Feeder is shown in Figs. 1 and 2, Plate 85. A pair of bottles BB, feeding the boiler alternately, are centred on opposite sides of a horizontal axis A, upon which they rock through an angle of 23° at each reversal. The centre boss C, which carries them, is a cast-iron or gun-metal circular disc, faced to work against a corresponding stationary disc D, which is fixed upon the bedplate of the apparatus; the whole being placed some 3 ft. above the highest water-level allowed in the boiler. The movable casting C communicates with the bottles B through the steam-pipes E at top, and through the water-pipes F at bottom. The stationary casting D receives all the four pipes through which the apparatus communicates with the feed-water tank overhead and with the boiler below. The top orifice G is the steam inlet from the boiler; the next below, H, is the exhaust outlet to the feed-water tank; the third I is the water inlet from the tank; and the bottom orifice J is the water delivery to the boiler. The steam pipe K, Fig. 6, Plate 87, which leads from the boiler to the top inlet orifice G, dips down inside the boiler to the exact level up to which it is intended that the boiler should be kept constantly filled with water. This pipe is furnished with a stopcock, as is also the supply pipe L from the feed-water tank; and there is the usual non-return or check-valve in the delivery pipe M to the boiler.

The action of the apparatus is as follows. Let us suppose the two stopcocks to be opened, in the steam pipe K from the boiler and in the water pipe L from the tank; and also that the water-level in the boiler is below the bottom of the dip-pipe K. The steam immediately passes up through the pipe K, and makes its way through the ports

of the two disc-castings into the top of the lower bottle, which is full of water. By the access of the steam to the top of this bottle, the water it contains, having the boiler pressure both above and below it, is set free to run out from the bottom, through the delivery ports of the disc-castings, and thence down into the boiler below. In the meantime, through the alternate ports of the discs, the feed-water from the overhead tank is entering at the bottom of the upper bottle; while, if any steam remains uncondensed in this bottle from previous working, it is escaping at the top, and bubbling up through the exhaust-pipe into the tank. By the time the lower bottle, delivering into the boiler, has about two-thirds emptied itself, the upper bottle has got filled up again to the top from the tank. The weight of the nearly emptied bottle, and also the friction between the two discs, being now overbalanced by the weight of the full bottle, the apparatus rocks over into the reverse position, whereby the whole of the ports are simultaneously reversed; the full bottle now delivers into the boiler, while the other refills from the tank.

The above alternate action continues until the rising water-level in the boiler seals the bottom of the dip-pipe K, thereby preventing the steam in the steam space from gaining access to the feeder. As soon as this is the case, the steam entrapped within the passages and in the top of the emptying bottle begins to condense; and the consequent fall of pressure induces a flow of water from the boiler, upwards through the pipe K, and into the top of the lower or emptying bottle, which is thereby refilled from the boiler without reversal. The two bottles being now both full, the feeder is incapable of rocking; and the further supply of fresh feed-water to the boiler is thus delayed, until the bottom of the dip-pipe becomes again unsealed by the falling of the water-level in the boiler. Under no circumstances however can the feeder continue permanently in equilibrium on a boiler that is giving off its steam; for the unsealing of the dip-pipe causes an immediate delivery of feed water from the lower bottle into the boiler, thereby destroying the balance, and causing the rocking to be resumed.

The feeder works equally well with hot or cold feed-water. In either case the sharp tilting over at each reversal has to be checked

and steadied by the dash-pots N fixed beneath each bottle. When the water drawn from the supply tank is cold, the delivery from the feeder, instead of going direct into the boiler, can be sent through an intermediate heater, placed in one of the subsidiary flues of the boiler. With the supply drawn from a cold-water tank, the boiler steam passing up into the tops of the bottles becomes condensed in them immediately; but when the supply is drawn from a hot-water tank, or direct from the feed-water heater itself, the uncondensed steam escapes from the bottles through the exhaust pipe, and bubbles up into the water in the tank or heater. An overhead supply-tank is not indispensable, if a supply of water under pressure is at hand; in that case the water service-pipe can with equally satisfactory results be coupled direct to the feeder, without the intervention of a tank or ball-cock; and the exhaust pipe can be returned from the feeder into the water supply-pipe. The amount of steam pressure is immaterial to the working of the feeder: its action is produced solely by gravity, and is due to the supply tank being above the feeder, and the feeder above the boiler. Thus the feeder will even work on a cold boiler, before there is any steam; but in this case it is necessary to open a small outlet in the top of each bottle for the escape of the air, which would otherwise remain entrapped there and would stop the action. In regular working, when the boiler is under steam, these outlets are closed by two small screwed plugs PP.

The two disc-castings C and D are faced slightly conical, as shown in the transverse section, Fig. 2, Plate 85; and are held together by a set-screw A, bearing against the end of the centre-pin on which the movable disc C rocks. As the boiler pressure tends always to part them, they work together with the slightest possible friction, and keep their faces so true as to do without any packing. A shallow annular groove is turned in the face of the stationary disc, into which fits a projecting ring on the face of the movable disc; any trifling leakage between the faces is caught in this baffle groove, and drains into a cup at bottom, and thence into the dash-pots N, from which an overflow pipe is provided at R, Fig. 1. The dash-pots are thus kept automatically supplied with water.

The arrangement of the ports in the two discs is shown in Figs. 3 and 4, Plate 85, which represent the obverse of the stationary disc and the reverse of the movable one. The ports are all radial, to suit the rocking motion of the movable disc. In the stationary disc D, Fig. 3, the middle port of the three smaller, which are above the centre pin, is the steam inlet G from the boiler; while the two on either side of it unite, and exhaust to the tank through the outlet H, Fig. 2. Of the three larger ports below the centre, the middle one is the water delivery J to the boiler; and the two on either side of it unite, and communicate with the water inlet I from the supply tank. In the rocking disc C, Fig. 4, the two lower ports communicate with the bottoms of the bottles, right and left respectively; and from the two upper ports pipes communicate with the tops of the bottles, but crossing one another, so that the right-hand port belongs to the left-hand bottle, and conversely. The ports in the discs are always open to the bottles, as well as to the boiler and the supply tank; and the rocking of the apparatus alternates the communication with each bottle.

The feeder shown in Plate 85 is suitable for a boiler of about 100 HP. The bottles are $18\frac{1}{2}$ in. diameter, and hold about 13 gallons each. The lower ports, for the passage of the water, are each $1\frac{3}{8}$ sq. in. area; the pipes are $1\frac{3}{4}$ in. diameter, excepting the steam dip-pipe, which is only 1 in. diameter.

In Fig. 5, Plate 86, is shown an application proposed by the author for a range of six boilers, each 18 ft. long and 6 ft. diameter, divided into two groups of three, each group having its own feeder. In case however of either of the two feeders being stopped from any cause, the other is large enough in itself to supply all six boilers; in which event the two valves A and B, on the steam and water mains, would have to be opened. The six boilers are of course all on the same level, and being all connected, the steam supply for the feeder need only be taken from one of them.

In Fig. 6, Plate 87, is shown the arrangement of the feeder for a single boiler of the Galloway type.

In Fig. 7, Plate 87, is illustrated the application of the feeder to

the boiler of a semi-portable or electric-light engine; and in Fig. 8, Plate 88, its application to a vertical boiler.

One of these feeders has now been in constant work at the Chaillot pumping station of the Paris Water Works since February 1880, without undergoing any cleaning or repairs; it delivers about 440 gallons per hour, the reversals occurring about every 75 seconds. At Messrs. Bourgin & Co.'s bleachworks at Courbevoie, near Paris, the feed is about 660 gallons per hour, with rockings every 45 to 50 seconds. In London the feeder has been working under the author's supervision since December last, on a 20-horse boiler at the works of Messrs. George Wailes and Co., Euston Road; in which the rate of evaporation is so much slower that the reversals generally occur only once every three or four minutes. In the inventor's early trials, the bottles were made of cast-iron, and consequently much thicker than the copper or wrought-iron bottles now used; the condensation of the steam in the bottles was thus rendered very slow, and practically the apparatus would not work until the thinner material now adopted was resorted to.

The Fromentin feeder is perfectly automatic, requiring no attention whatever in working. It maintains the water in the boiler at a constant level, supplying a continuous feed at exactly the same rate at which the evaporation is taking place, whether rapidly or slowly; it thus not only renders the boiler far safer to work, but also tends considerably to economise fuel and to increase the durability of the boiler. Owing to the quiet action of the feeder, and its extreme simplicity, there is practically no wear and tear, and no liability to get out of order; in this respect it is superior to both pumps and injectors, the former of which are subject to great wear and tear, while the latter are so liable to get out of order and cease working that they are most commonly supplied in duplicate—the second to be always in readiness whenever the first fails. A bell or whistle can be attached to the feeder, to be sounded by each rocking of the bottles, so as to call attention to the regularity of its working. It has no packing, glands, or stuffing-boxes, and requires no lubrication.

In consequence of the return flow of water from the boiler into the feeder through the steam dip-pipe, which takes place at intervals, the feed-water, even in the absence of any separate heater, is raised to a high temperature prior to its delivery into the boiler. This temperature, which varies of course with the boiler pressure, has been found in practice to range between 250° and 275° Fahr. on the French boilers already referred to. When the feed-water has not already been purified, prior to reaching the feeder, any salts of lime which it may hold in solution become precipitated at these high temperatures, as pointed out in Mr. Strong's paper read at the Newcastle Meeting last year (Proceedings 1881, p. 539). This precipitate however does not settle in the feeder, but is carried forwards by the water into the boiler, where it settles as mud, to be removed each time of cleaning out. The recurrent return-flow sweeping through the feeder keeps all the pipes and passages clear.

In conclusion, the author may remark that any further important advance in economy of steam power may be expected to be realised in future from the boiler and its adjuncts, rather than from the steam engine, which appears already to have attained very nearly the utmost degree of perfection within reach of actual practice. For this reason any device which serves to improve the efficiency of the boiler would seem to deserve special attention.

Abstract of Discussion on Automatic Boiler Feeder.

Mr. Hayes exhibited one of the feeders, together with a small model; and also drawings of arrangements to be used in cases where it was desirable to vary the level of the water in a boiler from time to time. Two arrangements were shown, Figs. 9 and 10, Plate 88, by which in such cases the level could be altered with the Fromentin feeder. In the one, Fig. 9, there were simply two dip-pipes of different lengths, with a cock to each; in the other, Fig. 10, the

dip-pipe was a telescopic tube, worked by a screw, and passing through a stuffing-box. It was very seldom necessary however to vary the level in a boiler, except between two points, high water and low water; and this could be accomplished by having two dip-pipes inside the boiler, as in Fig. 9, going down to the two levels.

Before the discussion commenced he would ask leave to read part of a letter from a very eminent man, M. Tresca, Honorary Life Member of the Institution. Knowing that M. Tresca had had a good deal to do with the Fromentin apparatus, he had written to him before the meeting at Leeds, where the paper was to have been read, and his reply was as follows:—

"I fully purposed attending the Leeds meeting of the Institution of Mechanical Engineers, but am unfortunately prevented by the state of my health.

"Of the Fromentin apparatus I have personally no knowledge based on long practice; but M. Couronne has kept me acquainted with his experiments, the results of which are as follows:—

"1st. Since the rubbing faces were made conical, the feeder has continued working in a perfectly satisfactory manner for more than a year without stoppage.

"2nd. The shocks occasioned by the filling of the bottles are sufficient to disperse all the scale that would tend to form. They produce no ill effect; and I can only attribute them to variations in pressure of the steam, which is in contact with water not heated to the same temperature; and perhaps also to the small size of the pipes.

"3rd. The conditions of the feeding are quite satisfactory as regards economy. I cannot say that the apparatus shows any distinct advantage in this respect as compared with feed pumps; but with the latter, even a moderate uniformity of feed cannot be ensured."

He regretted that M. Tresca's continued ill health had prevented any further information being obtained from him. He might also be permitted to read the communication upon which M. Tresca's remarks were partly founded, being a report to him by M. Couronne, engineer of the Paris Waterworks.

"Paris, 10 August 1882.

"Dear Sir,—You have done me the honour of asking my opinion of the Fromentin apparatus; the duties of my post have not allowed me to reply as quickly as I should have wished. The apparatus, fixed on one of the boilers at Chaillot, has worked in a very regular manner from the 28th February, 1880, to the present date; it has worked altogether 11,560 hours (including night and day work). I will not go into the details of its working, with which you are well acquainted; I will only draw your attention to a phenomenon which takes place when the limit of water-level is attained.

"At this time the water from the boiler is heard to enter with a sharp noise the bottle which is emptying; and this occurs several times consecutively. This is what M. Fromentin calls the 'Returns of water.' The following is, I think, a plausible explanation.

"The water in the boiler being at its highest level, the water in the bottle that is emptying is not at the temperature of the steam; the steam and water tend to attain an equilibrium of temperature, and thus there is a condensation of the layers of the steam in contact with the water, which is not more than 176° Fahr. At the same time the entrapped steam by cooling tends to lose its pressure, and then oscillations take place (as we have proved by a water gauge). In these varying conditions, there is a moment when on a sudden a relative vacuum takes place above the water in the bottle, and the water from the boiler then rushes up with noise into the bottle, to descend immediately to the same level as before; it is only when the water in the bottle attains the temperature of the steam that the phenomenon ceases.

"When these returns of water are too violent, they are easily moderated by partially closing the cock on the steam dip-pipe.

"My opinion is that steam at 305° Fahr. will condense partially in water not above 194°.

"In any case, these returns of water, far from being a disadvantage, serve on the contrary to clean the feed pipes; and we have frequently remarked that the ports of the discs and the interior of the bottles are completely free from calcareous deposits.

"We have only found these deposits at the opening of the pipe called 'barbotteur,' (*i.e.* the exhaust pipe, or outlet for the steam to the feed-water tank.*)

"We could not test the economy due to the use of this apparatus at our place (the Paris Waterworks) where the work of the boilers is regular and the action of the feed pumps is therefore constant; but at works where the amount of steam used is irregular, and where the feeding is done by a donkey pump or a Giffard injector, at very irregular intervals, it can be easily conceived that the use of the Fromentin system, by putting an end to the influxes of cold water, will cause an economy. This I have been able to test at M. Bourgin's cloth-dressing works at Courbevoie, where the saving due to the feeder, carefully verified, has exceeded 8 per cent.

"Couronne."

The President enquired if the apparatus had been tried with dirty water.

Mr. Hayes replied that the water at Messrs. Wailes' in London was not particularly clean, and the apparatus had been working there since last Christmas.

Mr. J. Hawthorn Kitson said that in order to show the apparatus during the Leeds meeting, he had put it on one of his boilers, and had it at work about a fortnight. It worked with perfect regularity and very satisfactorily. He took it off because his boilers were fed from the town mains, without the necessity of any apparatus at all. From his experience he believed that the apparatus was thoroughly

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* The author points out that, in the original design and construction of the Fromentin feeder, the two exhaust ports, in the fixed disc, formed a horse-shoe shaped chamber, which offered considerable resistance to the escaping steam, as seen in Fig. 2, Plate 85, at H; this horse-shoe chamber is now dispensed with in the later designs (as seen in the apparatus exhibited at the meeting), a movable cap at the back of the exhaust ports being substituted. By this means the ports are easily accessible for examination and cleaning, and it is found in practice that no deposit takes place.

reliable, and he thought it would be specially useful in forge boilers, where there was a very great risk of the attendant neglecting his duties, and of accident from the water-level becoming too low. The water-level was maintained by the apparatus with absolute constancy. He could not however agree with the proposal to place a range of boilers in connection with one feeding apparatus; because from experiments he had made he had found that the pressure within a range of boilers varied so much from one to another that it would cause too great a fluctuation of the water-level. He had one range of four forge boilers; and on testing them he found that, although the steam pipes were of the ordinary accepted sizes, yet, some of the furnaces being worked hard and others at a much lower temperature, there was a variation of 6 lbs. in the steam pressure between one boiler and another. Therefore, if those four boilers had been in connection with the same feeder, one would have been absolutely empty, while another would have been filled with water.

The President asked what was the boiler pressure.

Mr. Kitson said that in one boiler it was 46 lbs. and in another 52 lbs. per sq. in. The boilers were in connection with other boilers in the works at the same time, and the *average* pressure was the same in the one range of boilers as in the other. The boilers were only 14 ft. long, with 2 ft. 6 in. flues and 5 in. steam-pipes. That was as large a diameter of pipe as would generally be accepted, and still there was a variation of 6 lbs. between the hardest worked boiler and one that was being fired gently. He was bound to say however that the variation surprised him very much.

Mr. F. W. Webb asked whether the steam pipes were independent, or were all open to the same main pipe; and how the accuracy of the pressure-gauges was tested.

Mr. Kitson said the steam pipes were all open together. He had checked all the gauges by a special testing pressure-gauge which he put on the same branch as the ordinary pressure-gauge of

the boiler; and having tested the gauges, he then read off the pressures from them all at the same time.

Mr. E. B. Marten asked whether at Leeds the apparatus was applied to a furnace boiler or to a fired boiler.

Mr. Kitson said it was applied to a fired boiler. He did not try it with furnace boilers, because the experiments showed that he should require four feeders for his four furnace boilers, and he was not prepared to go to that expense.

Mr. William Anderson said he had gone very recently to see the apparatus at Messrs. Wailes' works in Euston Road, where it had been put up last January. It was not at work when he arrived, nor had it been for some little time—not because there was anything wrong with the feeder, but because, as Mr. Wailes had informed him, it was not connected with a tank which was heated by the exhaust steam of his engine. He did not use it therefore, because he wished to feed with hot water instead of cold; but he said that it had worked very satisfactorily as long as it had been in action, and he set it going again in a few minutes. The only trouble they had had with it Mr. Wailes attributed to the use of boiler composition, namely that the wearing faces of the disc-valve got out of order. But after these surfaces had been cut away, all except just what was necessary to make the connection between the ports, the faces worked very well indeed. Mr. Wailes confirmed what Mr. Kitson had stated with regard to the water-level being maintained very exactly; and he mentioned that the feeder, in consequence of this, had a ghostly habit of working in the night. When the water-level fell ever so little, either from leakage or from the water cooling and contracting, the feeder made one or two strokes in a mysterious manner. The impression left upon his own mind was that, supposing it to be desirable to have automatic boiler feeding at all, the apparatus was one which certainly accomplished the object the inventor had in view.

Mr. JEREMIAH HEAD said Mr. Anderson had doubted whether it was desirable to have automatic boiler-feeding at all. He wished to point out that, where a large number of boilers were fed by pumps, experienced boiler-minders seemed always to aim at making the arrangement as nearly automatic as possible: they regulated the inlet valves into the boilers, and set the donkey pumps going at a certain regular speed, so as to make the whole as nearly as possible self-acting. That seemed to him to prove that long practice showed automatic action to be the best thing, where attainable. For the human mind was not itself well adapted to become a mere machine; machinery should be made to perform all routine work possible, so that the human mind directing it might be in reserve, and ready to think and act, when and where it was necessary to deviate from mechanical routine.

He thought there was one great advantage in the apparatus, always supposing that it was practically found to work well: namely that you could see what water was being taken by the boilers; you could tell, by the speed at which the bottles were rocking, what the feeder was doing, and the evaporation that was going on. A case had lately come under his observation where there were a number of boilers, delivering steam into one range of steam pipes, from which several engines were supplied. The steam pressure often fell very low, and the machinery lagged behind. Under such circumstances it was not easy to tell what was at fault: it might be that the engines were using more steam, it might be leakages, or it might be that the boilers were producing less. But in the case to which he referred, the man who minded the donkey pumps said they were not going at their usual speed. That at once showed that the evaporation was not taking place in the boilers at the proper rate; and on further enquiry it turned out that the sweepers, whose duty it was to sweep out the boiler flues every Sunday (it was a case where the work was going on night and day), had been neglecting their work, and a portion of the boiler-heating surface was covered with soot. He mentioned this as showing that the donkey engine became a tell-tale as to what was at fault. He thought that the apparatus now exhibited would act in the same way.

On p. 479 it was said in the paper that some persons objected very much to the self-acting principle generally: preferring that men should be employed to keep watching, regulating, and assisting by constant supervision the operations of the machinery. He scarcely thought such a view was tenable. In the case of accumulators worked by hydraulic pumps, the self-acting principle had been universally adopted. The accumulator when it went up stopped the engines, and when it came down set them going again. The safety-valve was another instance of the same kind: and he might also mention the governor of the ordinary steam engine. He might go further still, and remind them of the time when the historical boy—Humphrey Potter—tied the valves of a Newcomen cylinder to some moving part of the engine, and so founded the idea of the eccentric.

Mr. Kitson had alluded to the apparatus being particularly adapted to forge boilers, where a constant level was always wanted. No doubt that was so; but he saw some difficulty in fixing it to that class of forge boilers which were vertical, and were in general set at a great height, perhaps 30 or 35 feet from the ground. It would be necessary there to have the apparatus perched on the top of a high column, and even then it would be necessary to have the feed-water tank still higher; or else it would be necessary to use the town mains, in which case the pressure was liable to be taken off at any moment.

There was one other advantage that he should like to point out, viz. that the apparatus might apparently be used as a water-meter, for testing the exact quantity of water going into a boiler in a given time. It appeared that the filling bottle went down, as soon as the difference between its weight and that of the other bottle was just sufficient to overcome the friction. Now, if that friction was a constant quantity, he did not see why there could not be an index something like that shown in Fig. 1, Plate 85, to tell not only the number of oscillations but also the exact amount of water evaporated in the boilers. That was a thing engineers had long wanted, namely, a simple and easy mode of ascertaining what evaporation was going on in any particular boiler per hour; and if the apparatus could do that, it would be, he thought, a very valuable addition

to their appliances. Of course such an apparatus ought to be accompanied with an alarm whistle on the boilers; because a workman, seeing it work steadily, week after week, without being looked to, would be apt to go to sleep at night, and depend entirely upon it. If the apparatus were then to stick, it would be very dangerous, and therefore some alarm apparatus to make a loud noise in case of sticking was desirable.

Mr. Arthur Paget was quite sure all present were impressed with the very great ingenuity of the apparatus; but he thought as practical men, instead of looking only at the mechanical ingenuity, they should consider whether, as compared with existing methods of feeding boilers, it was quite so far ahead of the present methods as the previous speaker had indicated, and as the paper itself would lead them to believe. He was a little astonished at the statement on page 479, that "the present system of feeding by means of pumps, injectors, and similar appliances, is attended with great disadvantages in regard not only to safety, but also to economy in working and in repairs." In his experience of injectors and pumps (though probably it had not been so great as that of many present), he had found them to give very little trouble, and to be very little liable to get out of order and require repairs. Looking at the automatic feeder as a practical engineer, he ventured to think that it was at least as likely to get out of order as either the injector or the pump.

Again, on page 482 it was stated that the two disc-castings C and D, Fig. 2, Plate 85, "work together with the slightest possible "friction, and keep their faces so true as to do *without any packing*. A "shallow annular groove is turned in the face of the stationary disc, "into which fits a projecting ring on the face of the movable disc." He should have thought that this ring was a packing; and the need of packing was confirmed by the statement that "any trifling leakage "between the faces is caught in this baffle groove, and drains into a "cup at bottom, and thence into the dash-pots N, from which an "overflow pipe is provided at R, Fig. 1." If an overflow pipe was necessary, it might be presumed that the dash-pots were provided

not only with sufficient water, but with more than they wanted. He thought it was possible that there might be quite as much trouble with those faces, in keeping them water-tight and yet not too tight, as in the case of the ordinary injector.

At page 484, after speaking of the condensation of steam in the bottles, the paper stated that "practically the apparatus would not "work until the thinner material now adopted was resorted to." To his mind that "told a tale," namely that, until sufficient heat was allowed to escape and be lost, the apparatus would not work. There must be a large amount of radiation from those copper vessels, which must practically mean a consumption of coal. Further on it was stated that practically there was "no wear and tear, and no liability to get out of order," which seemed an extraordinary pitch of perfection for any mechanical apparatus to have arrived at: while it was said that injectors "are so liable to get out of order and cease "working that they are most commonly supplied in duplicate." Now the injector, though a foreign invention, was practically born in Manchester; and he confessed to a certain feeling of respect for the injector, which would not allow him to let such a statement go forth without an emphatic contradiction. He did not think it was the general custom to supply injectors in duplicate, or that they could be said to be so liable to get out of order as to require it.

The statement, page 485, that the precipitate did not settle in the feeder might be very true in the case of some waters of a certain character, but he ventured to think that it would be very untrue with regard to most waters used for boilers: and until the apparatus had been tried with some of the sorts of water which formed the very tough and hard scales which were not uncommon, he thought it would be dangerous to assert that the pipes would not be liable to choke.

Mr. Charles Cochrane said he felt strongly the objections that had been offered to automatic feeding. He had had a boiler of the old balloon type at Dudley, to which the same man had been attending about 30 years. The feed apparatus simply consisted of the ordinary float and counterweight, with a head of water to feed, the steam pressure being only 6 lbs. The man had evidently acquired

such confidence in the arrangement as to trust to the boiler to feed itself; and one day the crown of the fire-box was forced down, and had it not been for the toughness of the plate there would have been an alarming explosion. The man had acquired an overweening confidence in an apparatus which had worked well for 30 years. It was a long time to work, but still it did fail at last.

Mr. Druitt Halpin thought there was some mistake in the concluding statement of the paper, namely that the steam engine "appears already to have attained very nearly the utmost degree of perfection within reach of actual practice." He thought that boilers which evaporated 10 to 12 lbs. of water per lb. of fuel, the fuel containing 10,000 to 12,000 thermal units, were doing very well; while engines using 2 lbs. of coal and 14 lbs. to 18 lbs. of water per I.H.P. per hour, were only utilising 15 per cent. of their thermodynamic efficiency: surely this went strongly against the statement put forward by the author.

Mr. Hayes, in reply, said, with reference to Mr. Kitson's remarks respecting a range of boilers, he thought that, if the steam pipes were sufficiently large, and the water connections direct, as they should be, and as shown in Fig. 5, Plate 86, there would be no difficulty in maintaining an equal pressure throughout the range. Only a few weeks ago he was at Woolwich Arsenal, taking particulars with a view to the application of the Fromentin feeder. The range of boilers there was six in number, as shown in Fig. 5, and the water connections were also similar. He examined the gauges, and he did not find a pound difference of pressure in any of the boilers. With reference to the remarks of Mr. Anderson, the feeder at Messrs. Wailes' works had been started by himself at Christmas 1881, and had worked regularly and without stoppage up to the end of July of the present year, when it was put out of regular work for the reason stated by Mr. Anderson; it had however been retained in position since that time, and put in action at intervals whenever required; and it could be seen working there by any Members interested. In that case the feeder had not been erected and set to work to take the

place of the ordinary system of feeding by pump and injector there in use, but merely as a matter of privilege and courtesy to himself on the part of Messrs. George Wailes & Co., to whom he was much indebted for their kindness; as likewise to Messrs. Kitson & Co., of the Airedale Foundry, for having generously granted him the opportunity of showing the feeder in action during the recent Summer Meeting at Leeds.

Mr. Head had suggested that the apparatus might make an excellent meter. With the view of carrying out that object, the apparatus had, as seen in Fig. 1, Plate 85, a recorder or counter, and also a scale. If a piece of wet rag, or a sponge, were drawn down the surface of the bottle, the steam in the top dried the moisture up at once, whereas the water below left it there; and it could thus be seen exactly how much water had gone into the boiler before the reversal took place. With regard to the suggestion of an alarm in case of sticking, of course he did not say that the apparatus could never stick; and until its use and application had become sufficiently general to establish confidence, there would be no harm in fitting an alarm apparatus to act in case of failure; similarly the application of this feeder to any boiler would not justify any steam user or engineer in dispensing with either fusible plugs or water gauges. It was only fair in the case of any apparatus, whether automatic or not, that when the boiler was cleaned the whole apparatus should be examined to see if it was all right. If that were done, say once in three months, he would give a guarantee with each apparatus supplied that it would not get out of order. It was not a mere matter of speculation. The letters which he had read at the commencement of the discussion gave the result of two years' actual experience; and that too from the highest and most impartial sources.

The President, referring to the question of deposit, said that at Elswick, for instance, the water was dirty, and gave a thick deposit: with such water he should be afraid lest, with the sort of give-and-take that there was in the water-level inside a boiler, the end of the dip-pipe might in time get choked up; and if it were so, that would

of course stop the apparatus. He should also like to ask whether the author had experimented on boilers that were apt to prime.

Mr. Hayes said he had not as yet had any experience with badly priming boilers, in connection with the application of this system of feeding. With regard to the dip-pipe getting choked, he had been inside Messrs. Wailes' boiler after six months' regular and constant working of the feeder, and had found there was a good deal of sediment in the boiler, but in the pipes of the apparatus and the bottles he had found no sediment whatever, the "returns of water" from the boiler keeping the whole quite clean internally, and free from deposit.

Mr. Paget asked whether the water used by Messrs. Wailes was from the canal, or from the mains; that is, ordinary London water pure enough for drinking.

Mr. Hayes said he believed it was from the mains; but of course London water, though pure enough for drinking, might leave a great deal of scale. As to the question of working and repairs, mentioned by Mr. Paget, the only working part about the apparatus was the face; and that was kept in splendid order simply because it was lubricated by the water itself. The apparatus required no lubrication, and no looking after. With regard to the leakage into the dash-pots, it was the fact that water did trickle down from the faces into them;—not because there was leakage, but because there was a small groove cut in the faces for that express purpose. Those dash-pots were an important part of the apparatus; and if they were not kept supplied with water, the result would be that every joint about the apparatus would be started in half an hour or less. A groove was therefore cut for the water to trickle into the dash-pots; otherwise there was no leakage, not even in the largest sizes. There was, he was bound to admit, a slight loss through radiation; but in spite of this it had been found by comparative tests against the pump and the injector that there was a saving of from 10 to 15 per cent. over both. That saving was brought about

no doubt by always maintaining an equal temperature in the boiler, and a constant level of water. It was shown, as regarded the injector, by the following statement, translated from the journal 'l'Ingénieur,' Paris, 28 October, 1882:—"At Messrs. Bourgin and Co.'s Bleach Works at Courbevoie a comparative trial has recently been made during fifteen working days, with an injector and a Fromentin feeder, under favourable circumstances, the boilers being but lightly worked owing to the slack season. The fire-grate area was 3·05 square metres; and the rate of firing was 200 kilograms of coal per hour, or 65·57 kilog. per square metre of grate per hour. The quantity of feed-water supplied by the Fromentin feeder was 1600 litres per hour, against 1400 litres by the injector; or 8 litres against 7 per kilogram of coal burnt: showing an advantage of 14·3 per cent. in favour of the Fromentin feeder."

Mr. Cochrane thought there still seemed considerable danger of the water forming a scale, and of that scale gathering about the mouth of the dip-pipe, and finally choking it up. He should like to ask whether the author had had occasion to deal with any such accumulation at the orifice of the pipe.

Mr. Hayes said he had had no such experience. After any length of time the pipe was practically as open as the day when the apparatus was set to work. Where however they did find some accumulation, say after several months, was at the end of the delivery pipe, inside the boiler. Each time the boiler was opened, that pipe should be examined. The velocity with which the water entered the boiler must necessarily be low; and hence the end of the delivery pipe in the boiler was the one point that ought to be watched about the apparatus. With regard to the dip-pipe there was no such danger. This feature of the end of the delivery pipe getting partially choked was not peculiar to any one system of boiler feeding, but was common in a greater or less degree to all. There was no real danger to be apprehended from this source, as the process of the pipe furring up was very gradual, and at the same time certain; it was therefore always looked for by the engineer in

charge of a boiler whenever it was opened for cleaning out, that is if he was a competent and careful man. If however there were any action going on at the mouth of the dip-pipe, as the President had suggested, sudden stoppage at the end of the pipe might at any moment ensue, and were this actually the case, it would amount to a serious objection against the Fromentin apparatus. But experience, the best guide, had proved conclusively that no danger on this head need for a moment be apprehended; so much so in fact that in fitting this feeder to any boiler, however large, they never put a larger steam dip-pipe inside the boiler than 1 in. internal diameter, whilst for all the other pipes about the apparatus, both water and steam, they recommended an increase in diameter of not less than fifty per cent. above what would be necessary if feeding with a pump or injector.

In reference to Mr. Cochrane's remarks, he quite understood and appreciated his objections, which he knew were also shared at present by others. But the comparison of the Dudley boiler was rather an unfortunate one, because he gathered it was the float attached to the feed apparatus of that boiler which had been the weak point, and which had eventually failed after thirty years. On the Fromentin feeder however there were no floats or levers, nothing but the dip-pipe inside the boiler; and it was not exposed therefore to any such risk.

With respect to Mr. Halpin's remark upon the concluding paragraph of the paper, he was fully aware that in practice the steam engine had not yet attained theoretical perfection; but he maintained that the Fromentin feeder was an advantage not only to the boiler itself, but almost equally so to the engine, since by its use, as already pointed out, the amount of water evaporated could be measured exactly, without trouble and without any additional apparatus other than that contained on the feeder itself: whereas with the pump or injector it was often found difficult, without special and accurate appliances, to check results of engine trials, and to show where the main want of economy lay, with the engine or with the boiler.

ON THE AUTOMATIC SCREW-BRAKE.

By Mr. W. PARKER SMITH, of London.

During the last few years large sums have been devoted to the task of replacing the hand screw-brake, in use on railways, by some form of continuous mechanical brake; and further expenditure is still being urged forward by the press, and also by Parliament and the Board of Trade.

In thus seeking to replace the old form of brake apparatus by one more suited to the requirements of traffic at the present day, it should be borne in mind that after all a continuous brake is simply an invention intended to perform more efficiently the functions of the hand screw-brake; that the latter has the merits of being very simple, reliable, and economical, always ready to perform its work, and never liable to fail unexpectedly at a critical moment. May we not reasonably demand of the apparatus which is to displace this hand brake, not only that it shall be able to bring the train to rest in a much shorter time, but that it shall do this without introducing any new element of danger? It is a very doubtful improvement, if we have discarded a reliable, though perhaps somewhat feeble, servant for a more powerful but occasionally untrustworthy agent. In fact the brake should be as reliable in action as the locomotive; and until such a result is obtained, railway managers have every reason to remain dissatisfied. We should have a very poor opinion of a locomotive which failed in stopping or in starting about once in every 14,000 miles it ran, thereby causing delay and inconvenience to traffic. Yet an examination of the Board of Trade returns shows that this is about the proportion of failures with some of the most approved and most carefully made continuous brakes.

The earlier forms of continuous brakes were mechanical: the rotation of an axle belonging to the guard's van caused a chain to be wound on a drum, or some similar operation to be performed, which applied the brake-block pressure on the wheels throughout the train. But the weak points in these or similar arrangements are twofold. In the first place the power that can be transmitted and applied is deficient; for although ample power is at hand, yet there is very serious difficulty in transmitting it through a series of spindles or linked chains. In practice the available brake-pressure that can be distributed through a train composed of many carriages is very feeble. Such a limitation must always arise when it is attempted to pass variable strains through many linked rods and chains; especially when it is necessary, as in the present case, that great freedom of motion and of change in relative position should be allowed to each part. The second weak point is that a failure in any one part may destroy the whole braking power. So far however as reliability of action is concerned, it is believed that an instance of failure with mechanical continuous brakes has scarcely been known.

It was a natural step to employ fluid pressure to transmit and distribute the braking power, in order to overcome the above difficulties; but fresh complications then arose, from the necessity of providing air-tight or water-tight connections throughout the system—a necessity especially troublesome where, as in this case, the connections are not permanent, and where flexibility of parts is required.

It has been the aim of the author to design a brake which shall combine with the reliability, and as far as possible with the simplicity, of the old hand screw-brake, the quickness of action and command of power attained, in the best examples of continuous brakes, by the use of high-pressure air, of vacuum, or of water. In the brake to be described (which has stood with entire success the practical test of a year's daily use on the Liskeard and Caradon Railway, Cornwall) these conditions have been attained by a return to the hand screw-brake in a modified form. The braking pressure is obtained, as in other mechanical systems, from the momentum of the train. The mechanism which actuates the brake on each coach is complete in itself; the pressure

applied to the brakes on any coach is due to that coach only; and the only continuous mechanism is a light chain, or series of spindles, which controls simultaneously the brake action throughout the train, and which is itself exposed to no strain beyond that necessary to lift a few small weights.

The apparatus consists essentially (1) of a screwed metal sleeve A, Figs. 1 to 6, Plates 89 and 90, loosely encircling an axle B of the coach, from which, by means of a coned friction-clutch C, it may be rotated when desired; (2) of a part-nut D, contained in a cast-iron box, which, by means of a cam E, Figs. 3 to 5, may be raised and lowered, so as to engage with and be disengaged from the screwed sleeve. A lever F performs by its descent and ascent the double duty of engaging and disengaging the part-nut; and also, when in its lowest position, acts as a wedge for forcing together the surfaces of the coned friction-clutch, as shown in plan, Fig. 6.

The action of the apparatus is as follows. If the lever is held up in its highest position, as shown dotted in Fig. 5, Plate 90, the part-nut is held up clear of the screwed sleeve, as in Fig. 3, and the surfaces of the coned clutch are not in contact. If the lever is permitted to descend by its weight to its lowest position, shown full in Fig. 5, the part-nut becomes engaged with the screwed sleeve, as in Fig. 4, and the surfaces of the coned clutch are also brought into contact by the wedging action of the lever. Any downward pressure applied to the lever in this position results in the screwed sleeve revolving, and the part-nut being carried to the right or to the left of its central position, according to the direction in which the axle is revolving. It will be seen by the plan, Fig. 2, that, with the double inclines on the pair of horizontal levers H H, a movement in either direction will cause the ends G G of the two brake-rods to move inwards, and so bring the brake-blocks against the wheels. For the purpose of obtaining downward pressure on the lever, and of graduating the friction between the surfaces of the friction cones, there is mounted loosely on the lever a sliding weight of about 10 lbs., W, Fig. 5. The lower the weight is permitted to slide down the lever, the greater will be the friction produced between the surfaces of the cones; and as the power which the screwed sleeve is capable of

exerting on the part-nut is governed by the amount of grip in the cones, it follows that by varying the position of the weight on the lever, more or less braking power may be obtained.

As soon as the desired braking power is attained, the pressure is relieved from the friction cones by lifting the weight on the lever; the screwed sleeve then ceases to revolve, but the nut still retains its position, and the brakes remain on. To take the brakes off, the lever must be lifted to its highest or dotted position, Fig. 5, Plate 90, thus lifting the part-nut altogether away from the sleeve, Fig. 3.

The apparatus is thus a multiplying machine, having a multiple of 2000, 3000, or 4000, as required. Instead of the engine-driver or guard having to operate, or the continuous connection to transmit, the whole braking pressure, in this system they have but to deal with small weights, which, by means of the apparatus, set in action the much greater power required for braking the train. The writer believes that the very satisfactory results he has obtained by this system are in a great measure due to the fact of the continuous connections having so little strain imposed on them. In every system the continuous connections will be the weak point; and the less work they have to do, the better will be the results obtained.

The levers and weights throughout a train may be controlled by a series of spindles with universal joints between coaches; or by having longitudinal rods under the coaches, joined together between them by chain, as shown in Fig. 7, Plate 90. The chain belonging to one vehicle is attached to that belonging to the next by an open link, as used with success in the Webb-Clark system. The pulleys K K are mounted in straps free to swivel in brackets bolted to the buffer planks of each vehicle; to the top of each strap is hinged an arm L. An eye is formed at the other end of this arm, through which passes a stud projecting from the centre of a circular plate J, Figs. 8 and 9; this plate has two notches formed in its periphery, and two projecting clips. A pulley M is mounted in a stirrup, free to swivel on a rod attached to the plate J. The mode of coupling up is as follows. The stirrup belonging to either of the arms is allowed to hang down, whilst the other is held up in a horizontal position, as shown in dotted lines on the left-hand side of Fig. 7;

when in these relative positions the clips on one locking plate are opposite the notches in the other, and can enter them; then, on permitting the stirrup hitherto held horizontally to descend to the position shown in full lines, the clips travel past the notches, and so secure the two plates together. In uncoupling, the stirrup is lifted horizontally, and the clips being thus brought opposite the notches, the locking plates J may be disengaged, and the arms L raised and secured by catches fixed at the end of each vehicle, as shown dotted in Fig. 7. It will be seen that this arrangement permits of the vehicles being turned end for end; and any alteration in their distance apart, due to compression of buffers or extension of draw-bars, does not practically produce any movement in the continuous connection.

Another design, shown in Figs. 10 and 11, Plate 91, embodies similar principles, but is specially suitable for vehicles with wheels of small diameter.

In this arrangement the screw is formed on a steel shaft A, which is suspended from the framing of the vehicle by hanging brackets B B. It is caused to revolve with the axle, when desired, by lifting an intermediate friction pulley, C, into contact with two friction pulleys D and E; D being keyed on the axle, and E keyed on the screwed shaft A. A lever F is used for this purpose, having a weight W mounted loosely on it, and free to slide along it.

The force with which shaft A revolves is regulated by the amount of friction between the pulleys D, C, and E, produced by the downward pressure applied to lever F. By permitting the weight W to slide down the lever, more or less friction may therefore be produced, varying with the distance it is allowed to descend. A part-nut, engaged and disengaged with the screw-thread of shaft A by cam gear similar to that employed in the arrangement before described, is connected to the brake-blocks by suitable connecting-rods and chains.

This system enables the lever to be kept higher off the road than if it were applied direct to the axle; it is also cheap, the total weight of the fittings being only $2\frac{3}{4}$ cwt.; and it requires no more lubrication than the ordinary hand-brake.

Fig. 12, Plate 90, is a diagram showing the general arrangement for controlling the brakes from the engine and from the guard's van; it also shows how the continuous connections may be utilised as a means of communication between the engine-driver and the guard. Referring to Fig. 5, it will be seen that the descent of the lever, from its dotted to its full position, may be considered merely as a preparatory movement before applying the brake; because the friction cones will not act, until the lever is in its lowest position and the weight W bears on it. This preparatory movement of the lever is useful in two ways. First, in any system where a slight variation in the length of the chain, or a slight movement in it, would result in the application of the brakes, there would undoubtedly be oftentimes inconvenience similar to that which is now experienced in the working of air-brakes, where a lowering of air-pressure in the main pipe results in the automatic application of the brakes. But in this system any such variation has not the same effect. Secondly, this action may be used for signalling between the engine-driver and the guard. A wheel, fitted with an adjustable balance-weight, is fixed in a convenient place on the engine, and is used for lifting and holding up the brake levers. Whenever it runs back, a cam fixed to its side strikes the hammer of a gong. A similar arrangement is fixed in the guard's van; but in this case the guard, in order to sound the gong on the engine, or to apply the brakes, must pull the continuous connection, so as to overcome the excess of the counterweight on the engine above the weights on the several levers along the train.

The writer does not claim as any novelty the principle of making each coach provide its own braking power. The "Heberlein" brake is similarly worked. He claims a great practical advantage in being able to disengage the friction clutch *without* taking off the brake. With the "Heberlein," the "Webb-Clark," and other brakes similarly constructed, during the whole time the brake is on there must necessarily be either skidding between the wheel and the rail, or between the friction-wheels which wind up the brake; whereas with this system there need practically be no skidding between the

surfaces of either, because with a little experience the engine-driver is able to lift the weight from the lever before the cones have lost their grip.

If, as in this system, the mechanism of each coach is independent in its action (except that all are simultaneously governed by one movement which stops or starts them), then the chance of an accident to the gear seriously affecting the entire train is very small, as compared with systems where the whole power is transmitted throughout the train, and where consequently a failure at one part will affect other parts.

When we consider the extreme complication rendered necessary by the application of compressed-air or water to brake purposes—the pumps or other apparatus to obtain the power, the main reservoirs, auxiliary reservoirs, connecting pipes and cocks, triple valves, brake cylinders and pistons, &c.—and when we remember that every one of these parts has to stand a pressure of some 80 lbs. on the square inch—we are indeed bound to admire the skill and ingenuity which have rendered practicable for such rough service machinery so delicate; but must still hold that railway brakes are no exception to, but rather an instance in point of, the general law, that the simplest means of attaining a desired result are the best. In those arrangements which by the production of a vacuum employ the unbalanced pressure of the atmosphere, such excessive strains on each part are indeed avoided; yet it is only at the expense of heavier and more cumbersome apparatus, and with the disadvantage of a slower brake action.

We may be quite certain that, given two machines constructed with equal skill and attended to with equal care, the use of the one of simpler construction will in the long run be attended with fewer failures. The more delicate and intricate the mechanism, the more careful and constant must be the inspection—a supervision difficult to obtain in any case, and especially so in the rough and arduous experiences of railway traffic working. Additional difficulties are introduced if the fittings are not easily accessible to inspection by the train examiners, or are such as to be beyond the skill of the ordinary carriage-lifter to repair. The durability of the materials used will also influence largely the question of safety, as well as

that of cost. Systems employing only metal will be generally recognised as more trustworthy than those in which india-rubber or leather have to be depended on.

With this system the brake is normally *on;* so that a coach fitted with this apparatus cannot be moved in either direction through even its own length, unless the lever is lifted and held up. Similarly, unless the continuous connections are perfectly made along a train, the levers cannot be lifted, and consequently the train cannot be started.

Again, any portion of the train that by an accident became detached would, by the automatic application of the brake, be brought to rest.

The movement by which the brake-power is applied, released, or graduated in amount, is made with ease and celerity; nor again is any appreciable time lost between the fall of the weighted lever and the application of brake pressure. From two to three revolutions of an axle are sufficient to put the brake fully on. It has been claimed by the advocates of compressed-air brakes that the full brake action is obtained, by the flow of air at high pressure, in $1\frac{1}{4}$ second: and they contrast this with the 10 seconds stated to be required before full pressure is applied by vacuum brakes. But even $1\frac{1}{4}$ second, at a speed of 60 miles an hour, means an advance of the train through 110 feet; whereas two or three revolutions of an axle represent an advance of but 20 and 30 feet respectively. Again, the screw-brake pressure may be retained for any length of time—an important consideration in descending long and steep gradients; while it can be taken off by the driver or guard at any moment if required.

The apparatus may be cheaply and readily fitted to any description of rolling stock, and admits of any approved method of mounting and hanging the brake-blocks. The weight of the apparatus complete is under 4 cwts.

The wearing surfaces are in all cases large. Those of the coned clutch measure 110 sq. in., while the wearing surfaces of the part-nut are larger than in the nut of the hand screw-brake. As many of the latter have been in daily use for twenty-five years past, exposed

equally with this brake to dust and dirt, there does not appear any reason why the part-nut should not have a long life. The author believes that, notwithstanding the large sums which have been expended in continuous brakes, there is still room for much improvement; but, even supposing that the results obtained by the working of air and vacuum brakes are not considered sufficiently unsatisfactory to warrant railway managers in changing their systems, there still undoubtedly exists a large field for mechanical brakes. Express goods trains should be provided with ample braking power, to enable them to be brought to rest in a reasonably short distance. Many of our colonial and Indian railways are at present provided with hand screw- or lever-brakes only, the use of which necessitates the trains being often brought to rest for the purpose of putting on the brakes along the train. Colliery proprietors would find an advantage in having their rolling stock fitted with a perfect automatic brake, to prevent them from running away on the steep gradients frequently existing on such lines; and there are many other cases where a cheap reliable brake will be found serviceable.

Abstract of Discussion on the Automatic Screw-Brake.

Mr. Parker Smith exhibited a model of a carriage-frame, fitted with this brake; also parts of the apparatus which had been in daily use in Cornwall for over a year.

The President was sure the members would agree with him that the subject of the paper was a very important one. Many present might remember that at the Institution dinner at the Leeds Meeting the chairman of the Midland Railway had called upon them as a body to give the Railway Companies a satisfactory brake. He hoped therefore that in this discussion the subject would be well

thrashed out, with the view of meeting the requirements of the Railway Companies; because certainly, as yet, with all the ingenuity that had been displayed in regard to brakes, there did not appear to be a thoroughly reliable and absolutely satisfactory brake in use. He asked how many miles the brake had run, and whether the stoppages were frequent.

Mr. Parker Smith said it had run about 13,000 miles. The train was only a short one of three coaches. There were three stations about a mile and a half apart, so that the stoppages were frequent; about 2400 stops had been made without a single hitch.

Mr. Jeremiah Head asked if the brake ever skidded the wheels, and what was the limit of pressure.

Mr. Parker Smith said it did not skid the wheels necessarily, but it would do so if too much brake-power were applied. The brake-power depended upon the position of the weight on the lever, and also upon the length of time the weight was allowed to remain on the lever. The weight should be allowed to remain on the lever sufficiently long to screw the part-nut through the exact distance which would give the pressure required, but no longer.

Mr. John Ramsbottom asked what was the nature of the ballast on the Liskeard and Caradon line; and also whether the screwed sleeve actually touched the axle.

Mr. Parker Smith replied that a great deal of the ballast was broken granite; there was but little sand in it. Some of the line was laid on granite blocks, and some on wooden sleepers. The inside of the sleeve did not touch the axle, as would be seen by the sleeve exhibited, in which the paint put on when the apparatus was new was unmarked. The sleeve was supported at each end by turned collars, Fig. 1, Plate 89, keyed on the axle and acting as bearings.

Mr. Ramsbottom was bound to say that he was not favourably impressed with the present design, having regard to the practical difficulties which presented themselves in actual railway working. It was one thing to have an arrangement adapted to two or three carriages, working under the eye of the inventor, and upon a line with good ballast; and it was another thing to apply it to carriages which might be put aside for weeks or months. In that case the working surfaces and the apparatus would naturally get rusty, and they were further subject to damage from being exposed to the weather, and to the dust which was always to be contended with in the case of long trains running at high speeds. Of course the fundamental principle of taking power to put on the brake from the momentum of the train itself was a sound one. The main advantage of the present arrangement lay in making it automatic, so as to apply the brake when the train from any cause was severed. The great difficulty however, in coupling up a number of carriages in a long train, was to arrange the couplings so that each brake should simultaneously do its share of the retarding work. That was a difficulty which he apprehended would have to be met, if this brake were applied on a large scale; and it appeared to him that the experience already obtained in reference to it was not sufficient to enable any one to speak with certainty as to what would be the result.

Mr. Joseph Tomlinson, Jun., said the brake question had been before railway engineers as a problem for the past ten years, and during that time as many continuous brakes had been brought forwards; but still it did not appear that any brake had yet been produced which would satisfy all locomotive engineers and so secure the adoption of a uniform system. The difficulty in most brakes was the number of pieces of mechanism to be kept in order and maintained; and, as Mr. Ramsbottom had pointed out, they did not adapt themselves to long trains. On the Metropolitan Railway he had adopted the Smith vacuum brake, with which all trains on that line had been fitted for the past six years; it answered its purpose well, and gave little trouble; in fact no accident of any kind had occurred during the whole time through any failure to act. The trains on the

Metropolitan Railway averaged 22 stops every hour; so that the total number of stops made during the time this brake had been used had exceeded ten millions.

The brake described in the present paper was a very ingenious one, and got rid of some of the difficulties belonging to the Clark-and-Webb and other chain brakes, namely that three or four revolutions of the wheels put the brake fully on, and so threw a sudden strain upon the chain, which necessarily caused at times a fracture. That objection had been got rid of in the brake now described, so far as the chance of failure was concerned; but still the action of this screw-brake was very quick and sudden. The difficulty which he himself felt was that all the blocks could not be kept in exact trim, and if they were worn unequally there would not everywhere be the same distance for the blocks to move to the wheel, when the brakes were put on, even though the nuts all came into action at the same moment; and hence violent jerks would be produced. It struck him that this was the inherent defect of all brakes put on in that way. In the vacuum brake, or the air-pressure brake, it was not so, because the action of the piston in moving forward was almost instantaneous, and the brakes practically came on together, whether the distance to be moved through was four or three or two inches.

Another defect of this screw-brake appeared to him to be that the stroke could not be very large, and hence the blocks would require to be frequently taken up: which on a line like the Metropolitan would be a very great source of trouble, and would require great attention.

Mr. Henry Davey said that a mechanical difficulty presented itself to his mind, in looking at the plan, Fig. 2, Plate 89, namely that it was possible to put a considerable pressure on the brake after skidding had taken place. He failed to see that the brakesman could have any idea of the amount of pressure that he was putting on the brake, beyond that necessary to skid the wheels. It appeared to him that the pressure which might thus be exerted by the screw on the part-nut, and so on the wheels, might be so great, if the friction cone happened to be a little rusty, as to endanger the

mechanism of the brake. And the amount of that pressure would vary with the condition of the brake-blocks; because if the blocks were new and very little worn, the nut would move very little on the screw before skidding took place. Again, he believed that the Liskeard and Caradon Railway, although passenger traffic was carried upon it, was to all intents and purposes a mineral line, with trains running very slowly and not very frequently: and therefore the experience already gained with the brake was not very large.

Capt. C. Fairholme, R.N., was glad to hear from the President that the Midland Railway wanted a brake; for while he had plenty of business on the Continent in relation to brakes, he had found great difficulty even in getting a hearing in England. With regard to what the paper said, p. 505, in reference to skidding with the Heberlein brake, he wished to point out that the power obtained was purposely limited, by the arrangement adopted, so that there should be no skidding of the wheel itself; and as to the skidding of the friction wheels, this in practice, since the adoption of crucible-steel friction-rings working against soft cast-iron axle-drums, did no injury whatever. For a long time they had had great difficulty in that respect, because they used wooden axle drums and cast-iron friction wheels. Then they went to cast-iron axle drums and chilled iron rings. The chilled iron answered extremely well for about six months, or till the chill was worn through, and then of course they were worse off than before. Since then they had adopted crucible steel, and all difficulty was removed, the friction rings becoming polished like silver, and there being no wear and tear worth noticing.

As to Mr. Parker Smith's brake, he admired it as being a move in the right direction; and the only part of the paper to which he might take exception was that referring (p. 500) to the "replacing" of the hand screw-brake. Certainly no air-brake could ever replace the screw-brake, because every air-brake was utterly useless without it, when separated from a locomotive with the necessary pump or ejector; and if coaches were left at night in a siding on an incline without screw-brakes, they certainly would not be found there in the morning. Again, the non-automatic vacuum brake, if the couplings broke on

a steep gradient, was utterly helpless without the hand-brake. His own aim had throughout been the same as that of the author, namely to place the brake mechanism upon each coach separately and get rid of the screw-brake. Great difficulty had been experienced with the old forms of the Heberlein brake, where there were continuous chains as in the Clark-Webb brake. No brake of that sort would ever be successful, because the coaches had not the brake-power each on itself. When he altered the arrangement, doing the same as Mr. Parker Smith had since done, but in a different way,— so that the brake was *taken off* by *tightening* the cord and *put on* by *slackening* it— then he was able to do away with all the chains under the coaches, and give each vehicle its own independent brake. The first thing now done on fitting a coach with the Heberlein brake was to put the screw-gear of the hand-brake on the scrap heap.

The author's brake would of course require some appliance to keep the lever lifted, in order to work it as a hand-brake; but it was easy to have some arrangement to hook up the lever in shunting, though it was not shown on the drawing. With reference to the brake couplings along the train, he had found, as a matter of practice, that nothing under the coaches would answer. The only practical way was to have a light line well guided by rollers above the coaches. Heberlein trains were daily being run in Germany with as many as fifteen or sixteen goods wagons between the engine and the passenger carriages, and nothing but a rope above would answer. Every carriage fitted for the system had its own piece of cord; and spare pieces were carried in the van, to go over vehicles from other lines. That was very necessary, because the trains were made up with all sorts of foreign vehicles, coming in at every moment, and these must be coupled in without any difficulty. As he was leaving the station at Berne a short time back, with a number of Swiss officials on the train, two cattle wagons had unexpectedly to be forwarded, and he told the driver to uncouple the engine and fetch them, and take them on between the Heberlein train and the engine. This was done without the smallest delay, and the Swiss officials were greatly impressed with the circumstance; and this special feature in the brake gained him at once two of the railways there.

The principal difference from the beginning between the Heberlein and the Clark-Webb brake was that the friction roller in the latter was on the wrong side of the axle; so that the strain of the chain was always tending to draw the friction roller out of contact with the axle-drum and thus take the brake off. This necessitated either a man to hold it on, or else some locking arrangement, which latter however at once deprived the engine-driver of the power of controlling the brakes. When the friction roller, as in the case of the Heberlein brake, was on the side of the axle opposite to the pull of the chain, its tension kept the roller in contact with the drum, and thus held the brake on, until it was again intentionally taken off by the driver by means of the brake-line. Hence the driver had only to shut off steam and let go the rope; he would thus drop all the brakes on, and then if advisable he could even jump off the engine, having done for his passengers all that a man could do. The action of the brakes in cases of necessity was almost instantaneous; whilst with long trains going down inclines of 1 in 30 or 40, as on the Elberfeld Railway, no difficulty whatever was found in controlling the brakes, and thus regulating the speed from the engine.

Mr. Thomas R. Crampton said, with regard to the injury that might be sustained by the brake apparatus through dust and through unequal wear, he should like to ask whether the screws did wear unequally, and whether, if one friction disc was more rigid than the others, that would have any effect in putting one brake on before another. It appeared to be a very important thing that all the brakes should go on simultaneously; he thought this might be provided for by some simple contrivance so that on the journey all would act together. With reference to dust, he thought the apparatus could afford to stand a little wear and tear; it was not one that worked continuously night and day, but only occasionally; and the friction caused by wear, he imagined, would not be very serious.

Mr. T. Hurry Riches said one objection had struck him with reference to the form of the coupling shown in Fig. 7, Plate 90, between the buffer-planks: namely that, when the brake-drum was

slacked off on the engine, as the buffers collapsed the chain pulleys coming together would tend to release the brake. Again, the use of chains revived one of the evils in the old Clark brake; chains always tended to clog and get out of order, and so disable the brake. He therefore strongly objected to chains on the carriages: besides being difficult to maintain in order, on any sudden slacking they had a tendency to get off the pulleys and jam.

He thought an automatic brake which was self-contained on each vehicle would be a most material step in the right direction. The best that he had seen was one that had lately been brought to his attention, introduced by Mr. Foulkes. It had about half the number of parts of the brake now described, in which the apparatus also seemed to be heavy for the work to be done, and must certainly be rather costly. They had not heard what the probable cost per carriage or per wagon might be.

The paper referred, p. 508, to the question of applying the brake to express goods trains; but he hardly thought this arrangement would be practicable, because the large amount of slack in the couplings, in the case of wagons, would entirely destroy the possibility of working such an apparatus as that shown. Then there was the question of the constant interchange of wagons between different companies, which rendered it very difficult to apply any form of continuous brake.

Mr. Parker Smith, in reply, said that Mr. Ramsbottom had remarked that the brake had only been tried on a small scale. It was his misfortune more than his fault that he had not been able to try it on longer trains. He could only say that he had found the brake worked equally well on three coaches as on one; and if he might take that as a basis, then it would work the same on nine as on three.

With the system of coupling shown in Fig. 7, Plate 90, and referred to by Mr. Riches, any variation in distance, due to the compression or extension of the buffers, or to their different heights, or to unequal loading, did not produce any movement in the continuous connection; it thus entirely overcame the difficulty which had hitherto been

experienced, and had been anticipated by Mr. Ramsbottom, in controlling a number of apparatus dispersed throughout a long train. Variations in the distance apart of vehicles, or in their relative heights, would alter the angle formed by the two links, but would not produce any movement in the chain. In illustration he would refer to an ordinary two-foot rule, the opening and closing of which did not alter its length. Again, the continuous connection was always in tension, because each of the weights on the carriages was pulling against the weight on the engine; and so, if you slacked out an inch in the chain on the engine, each weight along the train descended one inch. It was this fact which ensured simultaneous movement of all the levers. He could not agree with Captain Fairholme that a rope was the best connection. He had tried to avoid everywhere the use of perishable material. He had done away with leather and india-rubber; and until he found that the chain failed, which certainly had not been the case hitherto, he should not fall back upon the rope.

With reference to the question of exposure to the weather, dust, dirt, and the like, it should be noticed that the screw was protected by the nut, so that much dust could not get in. He did not see however why dust should affect this brake more than it did the hand-screw brake, which had been in use ever since the earliest days of railways, and had been found to work very well. If it were found there was any serious wear due to dust or dirt, the screw could be protected with a casing of sheet iron, or some means of automatic cleaning might easily be arranged. He had not done so hitherto, because he preferred having the apparatus open to inspection, so that it could be examined like the other parts of the train. The full sized parts exhibited showed how very slight was the wear; for, although they had been working many months and were made of soft cast-iron, the tool marks were visible on nearly the whole of the working faces.

As to getting unequal brake-power on the various coaches, he had yet to learn that perfect uniformity could be got with any description of brake, whether vacuum or compressed-air. He did not believe it; the power would vary slightly from coach to coach, with the distance between the brake-blocks and the wheels. He could prove that

anything which would prevent simultaneous application in his brake would produce the same result with other systems. Thus, supposing that of two coaches one had the blocks $\frac{3}{4}$ in. from the wheels, and the other 1 in. (which was always liable to happen), then, whatever the means of bringing the blocks against the wheels, one-third more time would be required to do so in the case of the second coach than in that of the first. Now the quickest action claimed in the compressed-air system was that it would put on the brakes in $1\frac{1}{4}$ second: during which time, at 60 miles an hour, the coach would have moved about 110 ft. Hence the first coach would have the brake on for one-third that time, or for 37 ft. distance, before the brake came on the second. But in his own brake the full braking power was put on in 30 ft. distance, whatever the speed of the train; and therefore the utmost distance that the first coach would run with the brake on, before the second had it on, would be 10 ft. only.

With regard to Mr. Tomlinson's objection that the action of the brake was very quick and sudden, the quickness of action was a great advantage, as was everywhere admitted. But he denied that the action was sudden, because the travel of the nut, being regulated by the pitch of the screw, was comparatively slow. For example, at 60 miles an hour, 3 ft. 6 in. wheels would make 480 revolutions per minute; but the part-nut would only travel at the rate of 480 in. or 40 ft. per minute. Hence the blocks would be brought against the wheels not suddenly, but gradually: and this gradual action was one great advantage of the screw for brake purposes.

Again Mr. Tomlinson was mistaken in thinking the stroke could not be large with this system. There was no difficulty in giving a travel even of 2 in. or 3 in. at the brake-blocks, if desired; and this was well known to be considerably more than was ever given.

Mr. Henry Davey had said that there might be considerable pressure after the wheels were skidded; but there need not be any skidding at all. One of his main objects was to avoid skidding, and in practice it was found that there was none. The amount of brake-power depended upon the amount of pressure between the friction surfaces; and that depended upon the weight bearing on the lever F, Fig. 5, Plate 90. Now the driver should never allow that weight to

remain on the lever after it had done its work. The balance wheel on the engine would be marked with graduations for the various brake-powers. If the driver moved the wheel sufficiently to unwind the whole of the chain, then each of the weights along the train would descend to the lowest position, Fig. 5, Plate 90, and would produce the maximum amount of brake-power. But by making the wheel move more or less, he could produce more or less braking power as desired. In any case, having allowed the weight to remain on the lever F for just a second or so, he brought the wheel half way back; by doing that he took the weight off the lever F, and removed the pressure from between the cones ; the brake was then left on, with the apparatus out of action. When he wanted to disengage the part-nut, he would then have to turn the wheel the whole way back; the nut would then be lifted clear of the screw, and the tension of the brake-rod would bring it back into the central position on the screwed sleeve.

With reference to cost, the apparatus complete weighed about 4 cwt. A great deal of it was of cast iron or cast steel, and it was not a very expensive class of ironwork to make, so that the apparatus need not be very costly. He had not as yet made it in sufficient quantities to enable him to say the lowest price it could be made for; but he should be prepared to fit up any train at one half the price of any compressed-air brake.

It might perhaps be premature to speak about continuous brakes for express goods trains; but he believed the day would come when some description of continuous brake would have to be fitted to such trains; and he was inclined to think that engineers would, when that time came, adopt a mechanical brake. He did not think mechanical brakes had as yet had a sufficient trial in this country to enable any one to form an accurate opinion respecting them; when they had such a trial they would be found superior in every respect to either compressed-air or vacuum brakes.

ON A CENTRIFUGAL SEPARATOR FOR LIQUIDS OF DIFFERENT SPECIFIC GRAVITIES.

By Mr. WALDEMAR BERGH, of London.

This machine, the invention of Mr. De Laval, of Sweden, is constructed for the purpose of dividing or separating from each other any two fluids of different specific gravity. Hitherto the machine has been specially constructed for the separation of cream from milk, so as to do away with the slow and often troublesome process of setting the milk. From a mechanical point of view the arrangement offers some interest; and the writer will therefore describe the machine as it is now made, after considerable improvements in the construction have been carried out.

The apparatus, Fig. 1, Plate 92, consists of a globular or cheese-shaped vessel A, opening above into a cylindrical neck, and mounted upon an axis on which it is rotated by means of a small pulley K. On the inner side of the cylindrical part of the vessel is fixed a small open tube B, which is bent round inside the globular part, so as to terminate where the diameter of the globe is greatest. A small orifice C, about $\frac{1}{8}$ in. diameter, leads out of this tube, and can be partially opened or closed by a small set-screw, Fig. 2. In the rim of the cylindrical part of the vessel is another orifice D, cut down from the top, about $\frac{1}{8}$ in. deep and about $\frac{1}{16}$ in. wide, Fig. 3. A cup E, to which a thin wing is fixed, is made to hang down into the cylindrical neck. The object of the wing, which is on the opposite side to the tube B, is to give the milk always the same velocity as the vessel.

The globular vessel is 12 in. in its greatest diameter, and the speed necessary to secure a perfect separation is between 6,000 and 7,000 revolutions per minute.

The milk is fed into the machine through the cup E, from which it enters the globular part A through a small tube F. On account of the high velocity of rotation, the interior surface of the rotating liquid takes very nearly the form of a vertical cylinder, and the cream is almost immediately separated, and forms a thin layer on the inside of this cylinder.

In the same proportion as the vessel is filled with milk, the inner surface of the liquid cylinder contracts in diameter; but no liquid will flow out until the diameter of the interior space becomes just equal to the diameter of the upper or cylindrical part of the vessel. It will then begin to rise by centrifugal force, and flow out of the two orifices D and C; that which flows through the orifice D being the innermost layer of cream, while that through the orifice C is the milk, which has passed up the tube B. The proportion of the areas of the two orifices will regulate the respective flow through each. If the orifice C is partly closed up by the set-screw, so as not to allow all the skimmed milk to flow out there, the cream will then be greatly mixed with milk, and flow out very thin; but if this orifice is left entirely open, the skimmed milk will flow quickly away through it, leaving the cream to flow out at D without the least mixture of milk. The two streams of milk and cream are caught in two tin covers, whence they flow out through tubes attached. The cast-iron arm G is used to keep the feeding spout central, and also, by the india-rubber washer at H, to deaden any vibration of the covers. The process can thus be continued as long as is desired.

The rotating vessel is constructed of the best Bessemer steel, made from Swedish iron. It is forged into the desired shape from one single sheet of steel; the spindle is then attached, being screwed into it at S, and bolted through the flange; and the whole is most carefully turned inside and outside. It is tested up to 250 atmospheres pressure before being put in the machine. To prevent vibration, the weights of the wing and of the tube B opposite are so proportioned as to preserve the balance.

By specially constructed friction gear the speed can be got up gradually. This gear consists of a wooden disc fast on the driving shaft, and a cast-iron disc loose on the same shaft. The latter can be

pressed against the former by means of a spring, and then gradually assumes the same speed: the rate at which it gets up speed being varied by screwing up the spring more or less. From the cast-iron disc a round leather strap $\frac{3}{8}$ in. diameter is led to the small pulley K, Fig. 1, Plate 92. On the top of the spindle J of this pulley is a step L, into which is rammed a lining of boxwood, Fig. 4, shaped so that the end of the spindle of the rotating vessel fits well into it. The upper bearing N is surrounded with an india-rubber ring, which arrangement prevents any injurious effects from vibration. The lower end of the spindle J is convex in shape, and rests upon the pivot on the upper surface of the block P, which is also convex. All the bushes are made of grey cast-iron. By this double arrangement of friction gearing it is possible to bring the speed up very gradually and steadily, even if the motive power should be unsteady. If the pulley K should be started too fast to allow the heavy upper spindle at once to attain the same speed, the only result will be that the spindle will slip in the wooden lining at L, until the same velocity is attained. As the cylinder rotates on the principle of a top, it will vibrate somewhat at starting; but when it has once attained its proper speed, not the slightest vibration can be observed.

The arrangements for lubricating the bearings are very simple. From the oil-cup O, on the side of the cast-iron frame, a tube leads into the groove on the top of the bearing N. From this groove the oil runs into the bearing, from the lower rim of which, by the rotation of the spindle, it is thrown outwards into the circular cup R, surrounding that part of the bearing. Thence through the tube Q it is carried down to the lower bearing T, from which the waste oil is again carried down to the pivot P, by the same arrangement as above described.

After having thus described the separator, it may be of interest to mention some of the machines previously constructed for the separation of cream from milk by centrifugal force.

The first attempt in this direction was made about twenty years ago in Germany. A disc about 4 ft. diam. was made to rotate horizontally at a high speed. Round the rim of this disc were fixed

strong iron hooks, on which buckets filled with milk were hung. After, say, twenty minutes' rotation, the heavier portion of the milk (or the skim milk) was forced to the bottom of the buckets, leaving the cream on the top. The disc was then stopped very gradually, so as not to disturb the cream which was floating on the milk. When the disc was brought to a standstill, the cream was skimmed off with a spoon in the ordinary way.

The next machine constructed was a great improvement on the first. This was a vertical cylinder, the top of which was partially covered, leaving only a hole in the centre. After the milk had been passed into the cylinder, the latter was made to rotate at a high speed; the milk was thus thrown to the sides, leaving a cylinder of cream in the centre. When the separation was considered complete, the machine was again stopped very carefully, and the cream which was left floating on the milk was skimmed off. It will be seen from this description that the separation of cream from milk could easily be effected; but no arrangement for drawing off the cream mechanically was used until some six years ago. A cylinder very nearly of the same construction as the last described was then employed, having on the top a rim extending inwards 4 or 5 inches. By the rotation of the cylinder the separation was produced as before. When the cream was formed, *skimmed* milk was fed into the machine, which, taking its place behind the cream, pressed the latter up and over the rim of the cylinder, where it was collected in a cylindrical receptacle round the machine. When the cream was all drawn off, the feed was stopped, and the cylinder emptied by means of a cock in the bottom.

Subsequently Mr. De Laval brought out his invention of a tube fixed inside the neck of the cylinder, and leading to the largest internal diameter, so as to draw off the skim milk, as shown in the drawing, Plate 92.

It will readily be understood that this machine, with some slight alterations, can be made to separate a great variety of fluids, as for instance in the purifying of oils, &c. An experiment was made some time ago at the Birmingham Gas Works with coal tar. The tar was taken direct from the scrubbers, strained, so as to take away the

grains of coke left in it, and was then passed through a machine constructed only for separating milk. In an instant the clear ammonia liquor was flowing out of the one spout, and the purest tar out of the other spout. Again, in one factory in Norway the machine is already in practical use for the purifying of fish oil.

Abstract of Discussion on Centrifugal Separator.

Mr. Bergh showed the working of the machine by means of a small model, which was run by hand at 8000 revolutions per min., one turn of the hand-wheel producing 300 revolutions of the separator. A good separation of milk and cream was produced, though not so good as could be effected by a full-size machine. One of the latter was also exhibited, kindly lent for the occasion by Messrs. Mather and Platt.

With regard to the experiments made at Birmingham with coal tar, he observed that the machine there used was not exactly like the one now exhibited. It was of the old type, constructed only for milk, so that they could not have expected such good results as they really got. It worked for half an hour without stopping; but there was a quantity of fine coke dust in the tar, which accumulated in the cylinder, and consequently in the course of time it got choked up. That of course was a difficulty which might possibly be overcome. A larger machine had been worked in Sweden, with a cylinder 24 in. diam.: it was worked six hours without stopping, and passed through six barrels of what was considered pure tar, from which it extracted nearly one barrel of ammoniacal liquor. There however the cylinder was also choked up after working the six hours.

Mr. John West said the beautiful model which had just been exhibited proved the utility of the process on a small scale; but the

question with him was whether it would be a practical advantage to the profession to which he belonged, that of the gas engineer. The separation of tar and ammoniacal liquor was not a very difficult thing to accomplish, as the tar soon settled down into the tar well; and he doubted whether it would be worth while to separate it by expensive mechanical means. The machine might however be used with advantage for separating the thicker from the lighter hydro-carbons in the tar, but that would be a question more for the distillers than the gas-makers. He should like to know what quantity would pass through a machine of given size per hour, so as to have some idea of the capacity of the apparatus that would be required if the process were adopted for the separation of ammoniacal liquor from tar. In Manchester, during the winter season, they would require to operate on about 52,000 gallons of tar and ammoniacal liquor per day; and that he thought would require a very large apparatus indeed.

But it had struck him, on looking at the construction of this machine, whether it could not be utilised for handling gas. The process now used to condense the particles of tar and ammoniacal liquor out of crude gas consisted in passing the gas through a series of pipes; but the whole of the tar could not be got out in that way; some of it would go forward with the gas, and unless some mechanical means were adopted to arrest it in its passage, it went on to the purifiers, and there gave trouble. He thought that if the gas were passed into the cylinder of a De Laval machine the tarry matter would fly to the outside and be taken out; so that there would be no necessity to resort to other mechanical means, to which some engineers thought there were certain objections. The method commonly employed was to pass the gas through a series of sieves covered with ammoniacal liquor, so as to wash it. The chief objection raised against this plan was the pressure required to force the gas through the sieves.

Mr. William Anderson said that the Royal Agricultural Society of England had thought the mechanical separation of cream and milk so important that last year they offered a gold medal for the best machine. This was competed for in July at the Annual Show

at Reading, and it had been his duty as their engineer to conduct the experiments. Unfortunately, from various circumstances, only two competitors appeared in the field — the De Laval, and another machine on the same principle, but in which the axis was horizontal. The De Laval machine obtained the gold medal; and it might be interesting to give a few of the facts upon which the judges founded their opinion.* The machine separated 53 gallons of milk per hour, and took $\frac{1}{3}$ H.P. to drive it, when running at full speed, or 6000 to 7000 revs. per min. It had a $\frac{3}{8}$ in. round leather band to drive it, and this band was only joined by a staple of wire—a proof of the extremely small amount of power which the machine required. The Society had set a limit to the quality of the separation, namely that no machine should leave so much as 0·4 per cent. of butter-fat in the skim milk; and the De Laval machine left 0·24, or rather less than $\frac{1}{4}$ per cent. It took three minutes on the average for the separation to begin, and it took thirteen minutes to clean the vessel out after the working was ended, *i.e.* at the end of the day's work; and then the milk left in the machine, which would have to be separated afterwards, was only $12\frac{1}{4}$ lbs.

He might add that nothing could be better than the way in which the machine worked, its perfect smoothness in running, and the total absence of any need of attention while it was in operation. He was very glad to be able to bear such testimony to what he believed to be a very valuable invention.

Mr. Henry Davey considered that this machine opened up a new field; and it was probable there might be many other applications of it besides those that presented themselves at first sight. One such application had suggested itself to him, namely the separation of metallic particles from flowing water. In mining operations a large amount of muddy water was usually produced by the stamping machines which pulverised the mineral, and much of the mineral was often so fine that it was capable of being held in suspension and carried away in the water. Cases had come under his notice in

* See Royal Agricultural Society's Journal, 1882, p. 623.

2 s 2

Cornwall where water from mines had been stored in ponds for the purpose of working water-wheels, and the sediment formed in the pond had been cleared out at certain intervals, and left there to accumulate for years on the bank; and where it had been found profitable to separate the mineral from that mud by passing it over what were termed "round buddles." * That was a very slow process, and consisted in passing the water through a revolving machine which distributed a film of it over a very large surface, and reduced the velocity of the stream to such an extent that the metallic particles were able to settle. It was necessary in lead and tin mines to pass the muddy water or slimes through three or four buddles in succession, before any considerable quantity of ore was got out. It appeared to him that, if passed through a machine like this centrifugal separator, the lead and tin particles would be immediately separated from the water. It would be necessary however to stop the machine periodically, to take out the deposit, the heavier portions of which, including the mineral, would be found nearest the sides of the vessel, because the heaviest particles would have the greatest centrifugal force. He would not say off-hand that it would be, commercially speaking, more profitable to treat slimes by that machine than by the round buddle; but he thought the subject was worth consideration.

Mr. Bergh, in reply, said he could not offer any definite opinion whether it would be profitable to separate coal tar in the way suggested; but it certainly struck him that if double the quantity of ammoniacal liqour, or liquor of double the strength, could be obtained by the process, there must decidedly be a gain; and the tar, he believed, was also very much purer. As to the purifying of gas, he had no experience himself; but no doubt the principle would be applicable to that case. As to the separation of particles from dirty water, that was perfectly easy, and had been already tried. Of course as the machine worked, the water would come out clear, while the solid residue would settle in the machine;

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* See Proceedings, 1881, p. 622.

and the machine would have to be stopped as soon as it got foul. Even in the separation of milk, the milk was to some extent purified, because there was always in milk some solid matter which it was impossible to strain out even with the finest strainers. Hence, when the machine had been working three or four hours, or even less, there would be found inside the cylinder a thin layer of greasy dirty stuff that did not properly belong to the milk at all, but was composed of fine hairs, skin from the animals and from the fingers of the milkers, &c. These foreign particles were taken out by the separator, and the milk was thereby purified. For that reason the butter or cheese made from milk so treated kept much longer than any other, because those impurities tended of course to hasten the putrefying of the product.

Mr. John Ramsbottom, in proposing a vote of thanks to Mr. Bergh, said that the paper had brought before them an interesting contrivance, which, he had no doubt, had presented itself to the minds of many as being capable of considerable extension and of wide application. So far as he was concerned, he did not see why it should not be applied to effect a more perfect separation of tar from gas.

EXPERIMENTS ON FLANGING STEEL PLATES COLD BY HYDRAULIC PRESSURE.

Communicated by Messrs. EASTON and ANDERSON, and published by order of the Council.

A pair of moulds, Fig. 1, Plate 93, were made to fit a hydraulic press, capable of exerting a pressure of about 250 tons. They were so shaped that at one operation they would make a flange both on the outside and inside of an annular steel plate, and thus produce a double-flanged annulus.

A taper was given to the moulds, as shown, to facilitate the removal of the plate after flanging. There was a slight hollow, $\frac{1}{8}$ in. deep, formed on the annular face of the upper mould, and a corresponding rounding on the lower one, to flatten the face of the plate. Experience showed that in this mould, and also in the second mould, Fig. 2, a depth of $\frac{1}{16}$ in. would have been sufficient.

The plates were Landore Siemens S. S. quality, $\frac{3}{8}$ in. thick. Their edges were bevelled in the lathe, to an extent of $\frac{1}{8}$ in. in the thickness on the inside, and $\frac{1}{16}$ in. on the outside edge; after flanging, a slight bevel suitable for caulking still remained. Both the outside and inside circles were cut out in the lathe.

These first moulds not proving altogether satisfactory, they were altered to the shape shown in Fig. 2, and turned on the working faces.

The first plate was successfully flanged cold, with a pressure of about 250 tons. In the second plate a little deeper flange was attempted, but it cracked at the inner flange. A plate of S. flanging quality was then annealed and tried cold; but it cracked in six

places on the inner flange. A similar plate not annealed also cracked, but in one place only.

Some more S.S. plates were then ordered, specially for this work, and were flanged cold and unannealed. The first one cracked in the inner flange; but this was probably due to an attempt to get a very deep flange, standing up about $2\frac{9}{16}$ in. from the underside of the plate; the next, with a flange of about $2\frac{3}{8}$ in. deep, did not crack. The third cracked at the bend of the external flange, on the outside, showing a crack about 3 in. long nearly through the plate.

A plate annealed for about four hours, and pressed when cool enough to be held in the hand, cracked badly at the inner flange. Two others, annealed for about sixteen hours, turned out quite sound.

A batch of twelve, heated in a plate-furnace and cooled in ashes for forty-eight hours, were then flanged with perfectly satisfactory results, there being no sign of cracking even on the inner edge of the hole, where the best unannealed plates had shown slight signs of skin cracks, started no doubt by the roughness of the sharp edge.

Another lot were annealed for about sixteen hours; but having had a thick layer of ashes over them, they were still warm when pressed. Out of four which were flanged, two cracked, one slightly on the inner edge, and one very badly.

The rest of these were put back to be carefully re-annealed, and out of fourteen twelve were sound.

In all these annealed plates, the actual duration of the flanging process in the mould had been very short, from $\frac{1}{4}$ min. to $\frac{1}{2}$ min. Another lot of twenty-one plates, thoroughly annealed, were now flanged, allowing the operation to extend over about $3\frac{1}{2}$ minutes: and at the same time the ragged edge round the hole was carefully filed off, so as to give no starting place for a crack. The result appeared to be satisfactory, as only two cracked, and those not badly.

The approximate thickness of the edge of the external flanges was $\frac{13}{32}$ in., showing an increase of $\frac{1}{32}$ in.; that of the internal flange was $\frac{5}{16}$ in., showing a reduction of $\frac{1}{16}$ in. The average pressure required for the annealed S. S. plates was about 200 tons.

It would seem as a general result, that for cold flanging, involving compression only, as on the outer flange, these plates, even of the

lower or S. quality, are perfectly trustworthy, even unannealed; as only in one case did a crack appear in the external flange. But for flanging involving considerable stretching of the material, as on the inner flange, only S. S. quality will do at all, and the slightest irregularity in the metal will cause a crack. The results showed that this might be expected in from 10 to 15 per cent. of the plates.

EXPERIMENTS TO ASCERTAIN THE STRENGTH OF CAST-IRON BEAMS FOR BEAM ENGINES.

Communicated by Messrs. EASTON and ANDERSON, and published by Order of the Council.

The object of these experiments was to find the co-efficient S in the formula $W = \frac{4ad}{l} \times S$ (a = area, d = depth, l = length), for a section suitable for cast-iron engine-beams. Four specimens were prepared and tested by Mr. Kirkaldy, who reported the results on 31st August, 1882.

In Table A appended, which gives an account of these experiments, Mr. Kirkaldy's numbering of the specimens is adopted; his figures are also given for—

(1.) The breaking load at centre in each case;

(2.) The breaking load at centre of test bars of the steel mixture;

(3.) The ultimate deflection;

(4.) The ultimate tensile and crushing strengths;

(5.) The specific gravity.

The dimensions of the specimens, the areas of the sections, the breaking weight of test bars of the ordinary foundry mixture, and the values of S, have been added by ourselves.

Two specimens, Q 2518 (Fig. 1, Plate 94) and Q 2519 (Fig. 2), were prepared, of the same form of section as that of an actual beam just outside the central boss, but of half the linear dimensions, and of a uniform section from end to end. The other two specimens, Q 2520 (Figs. 4 and 5) and Q 2521 (Figs. 6 and 7), were made like the same beam at the central boss (also half size),

but were continued on either side of the same section as the other two specimens. Each had the boss bored and a turned iron gudgeon forced in, half the diameter of the actual beam gudgeon. The pressure was applied to the gudgeons, and the resistance taken up at bearings 5 feet apart. In the case of Q 2518 and Q 2519, Figs. 1 and 2, the pressure was applied at the centre of the top flange by a blunt edge in the usual way. The top side, as in the sketches, was in each case in compression.

One of each form of specimens, Q 2518 and Q 2520, Figs. 1 and 4, were cast of the ordinary mixture used in the foundry; test bars made from this mixture, 2 in. $\times$ 1 in. thick $\times$ 36 in. span, generally break with 26 cwt. at centre, making $S = 2 \cdot 9$ tons.

The other specimens, Q 2519 and Q 2521, Figs. 2 and 6, were cast from a steel mixture as follows:—$\frac{1}{3}$ Landore mild steel scrap, $\frac{1}{3}$ No. 3 Calder pig, $\frac{1}{3}$ good cast-iron scrap.

Q 2518 (Fig. 1) had a flaw, at the fracture, in the bottom flange; hence it gave S too low ($= 2 \cdot 09$ tons only).

Q 2519 (Fig. 2) was sound, and gave $S = 4 \cdot 5$ tons, or rather greater than its value for the test bars cast from the same mixture, for which $S = 4 \cdot 337$. This is of course quite right, as the test bar had no flanges.

In the case of Q 2520 and Q 2521 (Figs. 5 and 7), the fracture started from close to the boss on the tension side, and went upwards towards the centre of the depth of the beam a considerable distance before actually entering the boss; it then passed laterally to the gudgeon, and finally went from the upper part of the gudgeon to the top of the beam, coming out nearly at its centre. Hence it was clear that the beams would have required a greater strain to break them through the boss from top to bottom; which would have happened if the web had been thickened up on each side of the boss. On the other hand, it would clearly not be right to take the actual area of the fracture for ascertaining the value of S. It was therefore considered best to take the area to be that of the vertical cross section of the beam at the centre, and deduce S therefrom, with the certainty that in reality S would be greater than the value thus assigned to it.

TABLE A.—EXPERIMENTS ON STRENGTH OF CAST-IRON BEAMS.

No of Specimen Shown in Plate 94	Q 2520 Figs. 4, 5.	Q 2518 Figs. 1, 3.	Q 2521 Figs. 6, 7.	Q 2519 Figs. 2, 3.
Area at Centre, sq. in. . .	70	35·75	68·2	37·8
Specific Gravity	7·0829	7·0829	7·3043	7·3043
Nature of Mixture	Ordinary Foundry	Ordinary Foundry	$\frac{1}{3}$ Landore mild steel scrap. $\frac{1}{3}$ No. 3 Calder pig. $\frac{1}{3}$ good cast-iron scrap.	Same as Q 2521
Ultimate Tensile Strength, Tons per sq. in.	8·27	8·27	14·13	14·13
Ultimate Crushing Strength, Tons per sq. in.	31·15	31·15	58·94	58·94
Breaking Load at Centre, Tons	140·45	89·08	232·47	203·04
Ultimate Deflection, in. . .	0·274	0·184	0·421	0·472
Calculated value of S for formula $W = \frac{4\,a\,d}{l}\,S$, Tons	1·66	2·09	2·84	4·5

NOTE.—Test bars 2 in. by 1 in., 36 in. bearings, from a similar mixture to Q 2520 and Q 2518, broke with about 26 cwts. at centre, making S = 2·9 tons.

Similar test bars, cast from the same ladle as Q 2521 and Q 2519, broke with 38·55 cwts. at centre, making S = 4·337 tons. Their mean tensile strength was ascertained to be 12 tons per sq. in.

These results were communicated to Mr. B. B. Stoney; and it is interesting to note his remarks thereon.

He did not approve of deducing the value of S in the way mentioned above. He considered that in each case the fracture had commenced in the lower or tension flange, at what was the weakest section, namely just close to the boss; S should therefore be found for the section of girder at that point (about 37 sq. in.), and the reaction taken as half the load acting at the end of the semigirder, about 2 ft. long. This would give S = about 2·5 tons for the ordinary cast-iron mixture, and about 4·3 tons for the steel mixture.

He remarked that the beam did not break through the boss, for only the upper part of the latter gave way; and that the boss might probably have been considerably lightened, without reducing the breaking load of the beam: thereby of course increasing the value of S as deduced from the section through the boss. He pointed out that the beam would be considerably strengthened by gradually tapering away the boss on either side down to the thickness of the web, without adding very materially to the weight of metal. But he remarked in conclusion, that the matter is one which simply needs special explanation; and if it is clearly explained that the section through the boss is taken for a special object, the value of S, thence derived, shows what similar beams may be expected to bear, provided the constant be taken in the same manner as in the present experimental beam.

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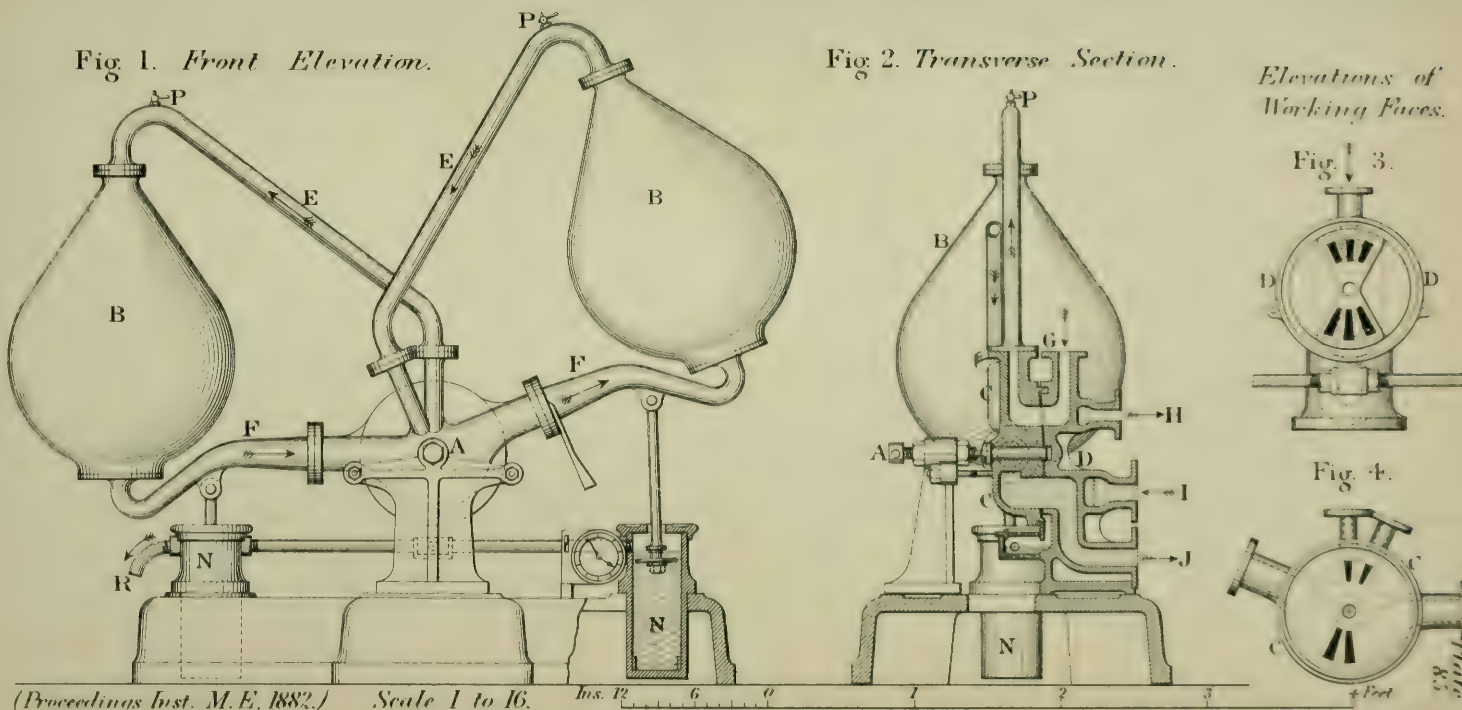
1882.

AUTOMATIC BOILER FEEDER.

Feeder for 100 H.P. boiler.

Fig. 1. *Front Elevation.* Fig. 2. *Transverse Section.* *Elevations of Working Faces.*

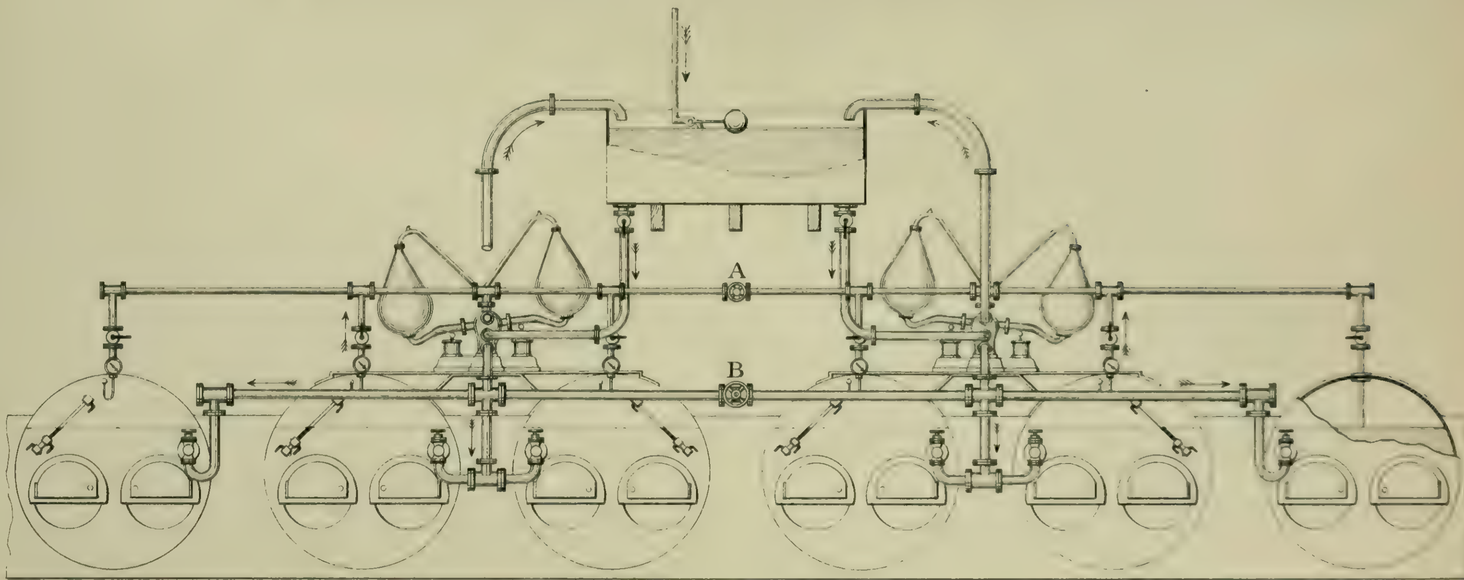


(Proceedings Inst. M.E. 1882.) *Scale 1 to 16.*

Plate 85

AUTOMATIC BOILER FEEDER.

Fig. 5. *Arrangement of Feeders for range of boilers.*



(Proceedings Inst. M. E. 1882.)

Scale 1 to 72.

Plate 86.

AUTOMATIC BOILER FEEDER.

Fig. 6.

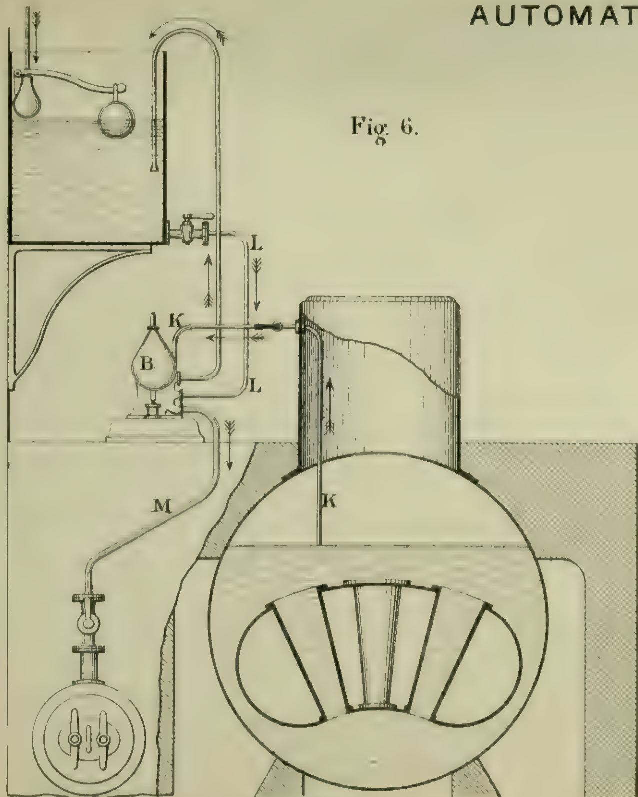
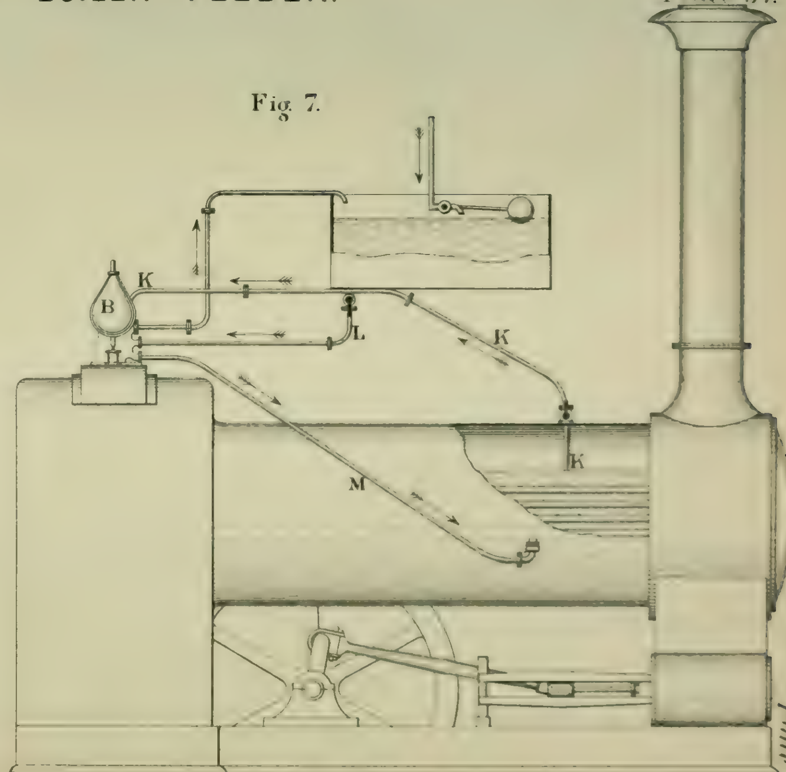


Fig. 7.



(Proceedings Inst. M. E. 1882.)

Scale 1 to 48.

Plate 87.

AUTOMATIC BOILER FEEDER.

Fig. 8.
Scale 1 to 48.

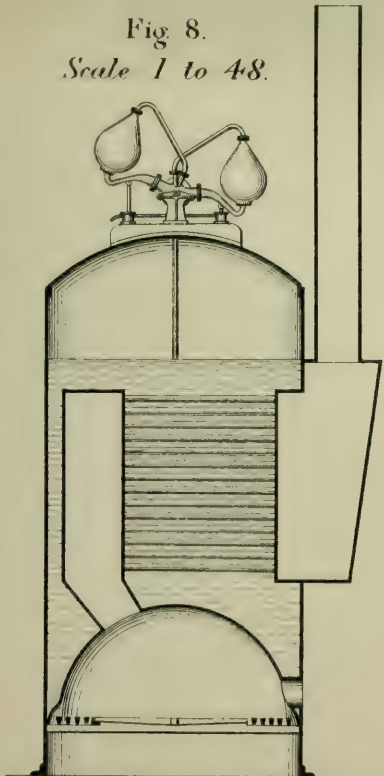


Fig. 9.

Scale 1 to 24.

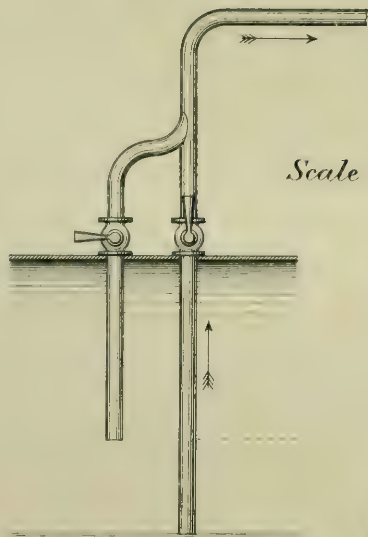


Fig. 10.

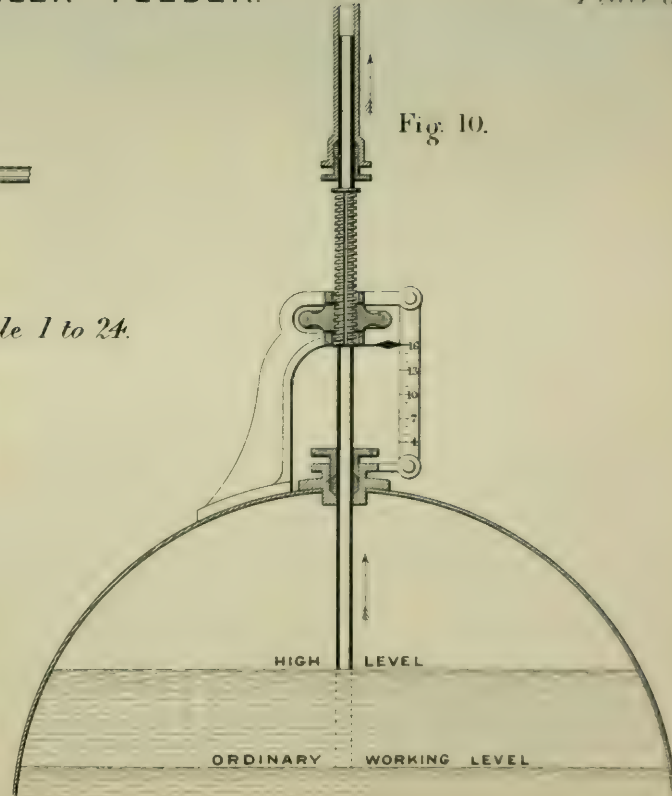


Plate 88.

(Proceedings Inst. M. E. 1882.)

Fig. 1. *Longitudinal Section.*

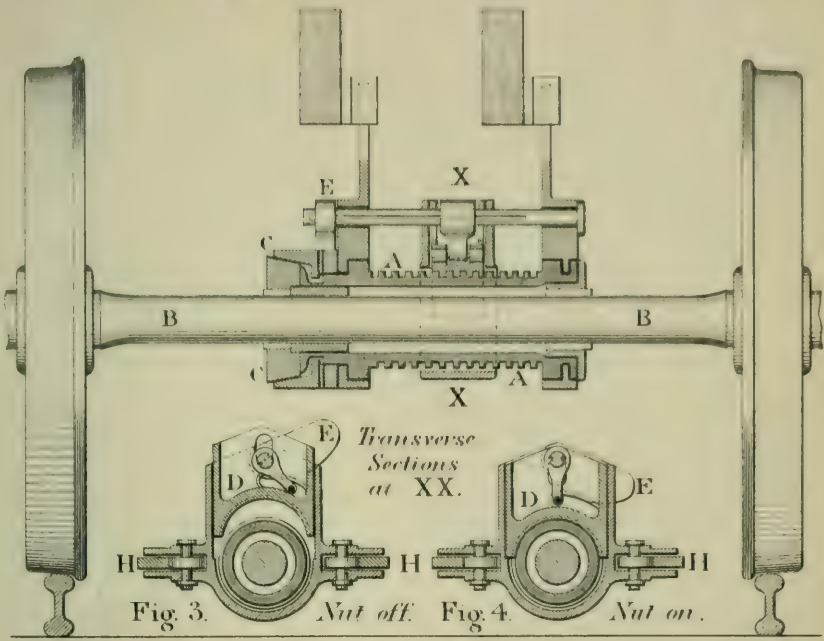
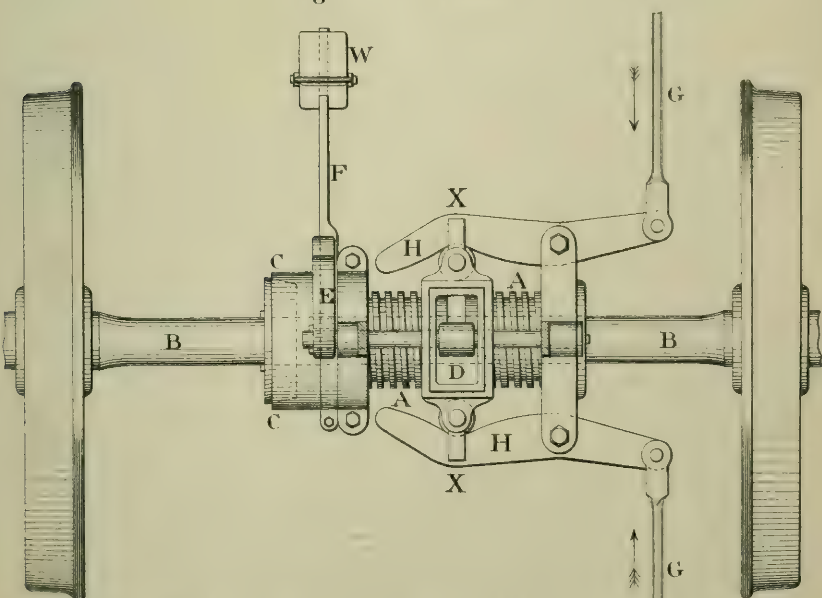


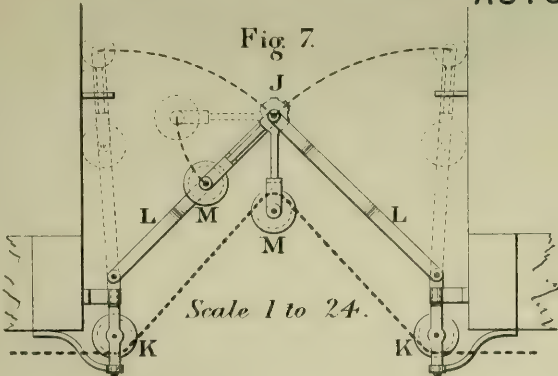
Fig. 2. *Plan.*



Scale 1 to 16.

AUTOMATIC SCREW-BRAKE.

Fig. 7.



Scale 1 to 24.

Fig. 8.

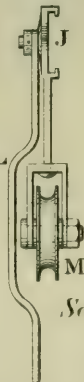
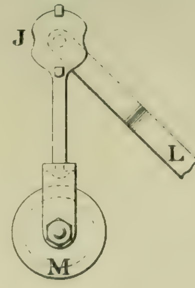


Fig. 9.



Scale 1 to 12.

Fig. 5.

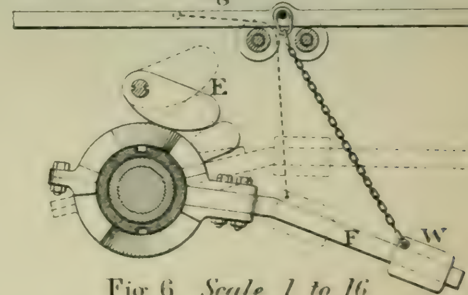


Fig. 6. Scale 1 to 16.

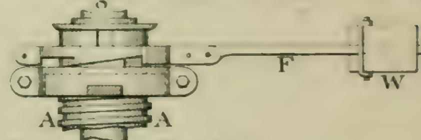
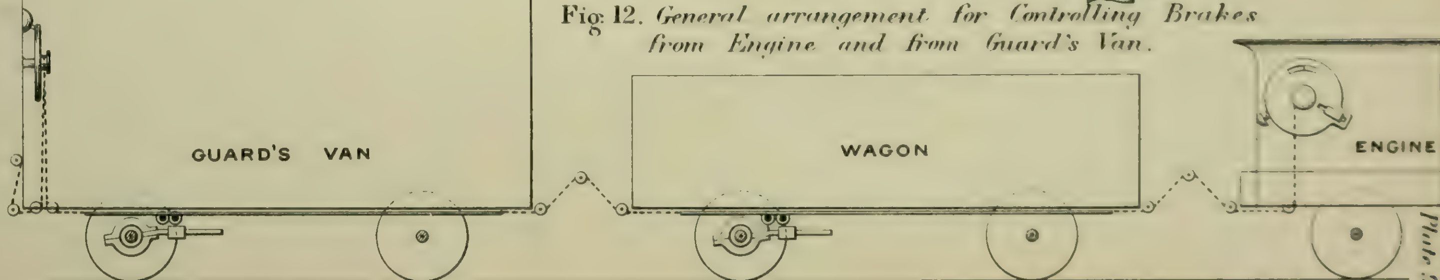
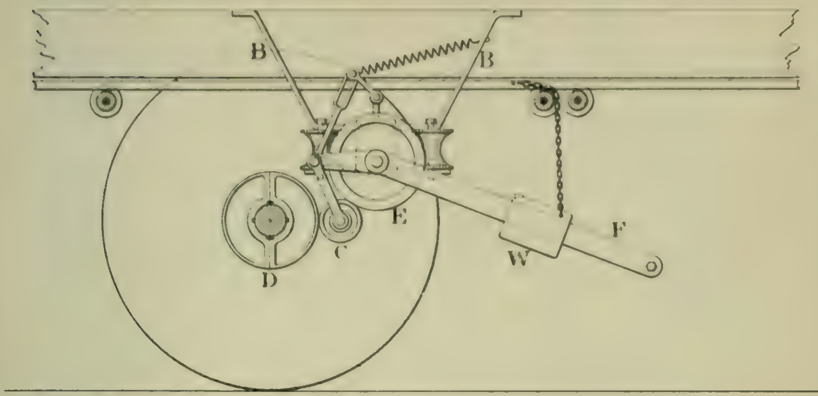


Fig. 12. *General arrangement for Controlling Brakes from Engine and from Guard's Van.*



Scale 1 to 60.

Fig. 10. *Arrangement for Small-wheel vehicles*



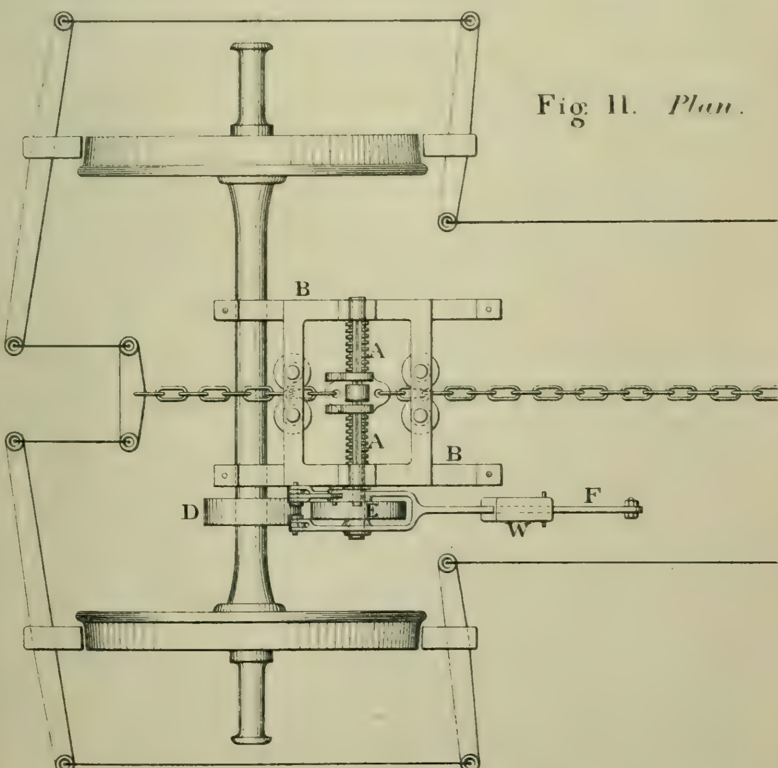


Fig. 11. *Plan.*

Scale 1 to 24.

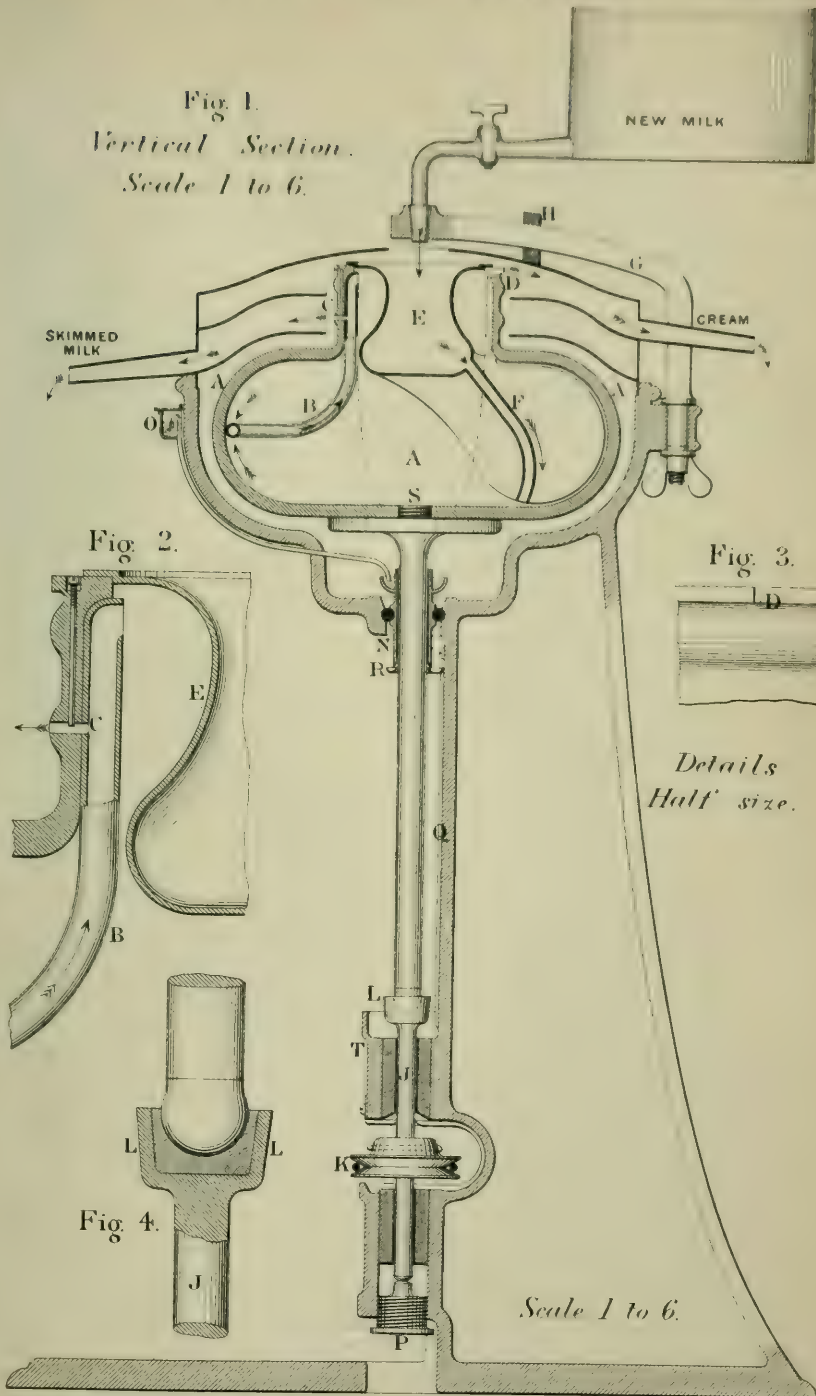


Fig. 1.
Vertical Section.
Scale 1 to 6.
NEW MILK
H
G
D
C
E
SKIMMED MILK
CREAM
A
O
B
F
S
Fig. 2.
E
C
B
Fig. 3.
D
Details
Half size.
N
R
Q
L
T
J
L
L
Fig. 4.
J
K
P
Scale 1 to 6.

FLANGING STEEL PLATES. *Plate 93.*

Fig. 1. *First Mould.*

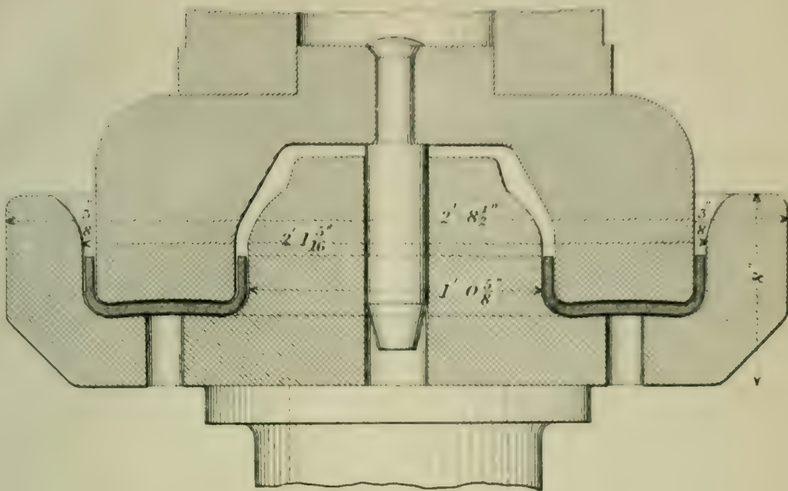


Fig. 2. *Second Mould.*

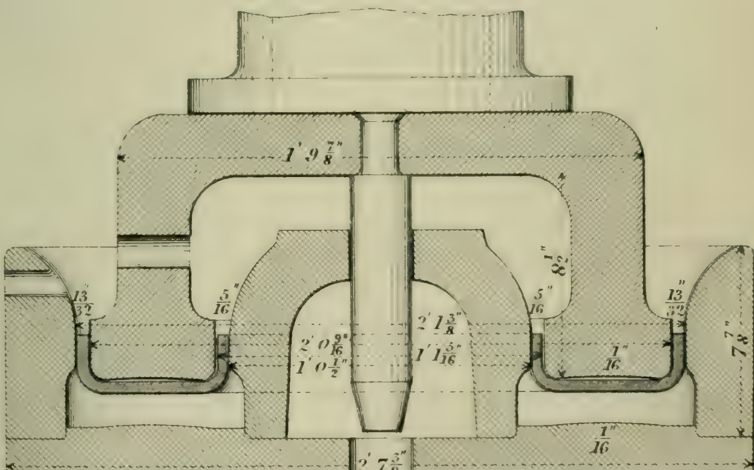
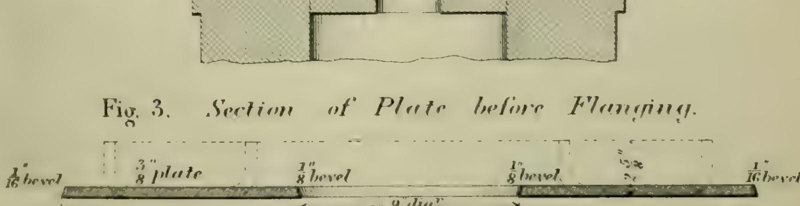
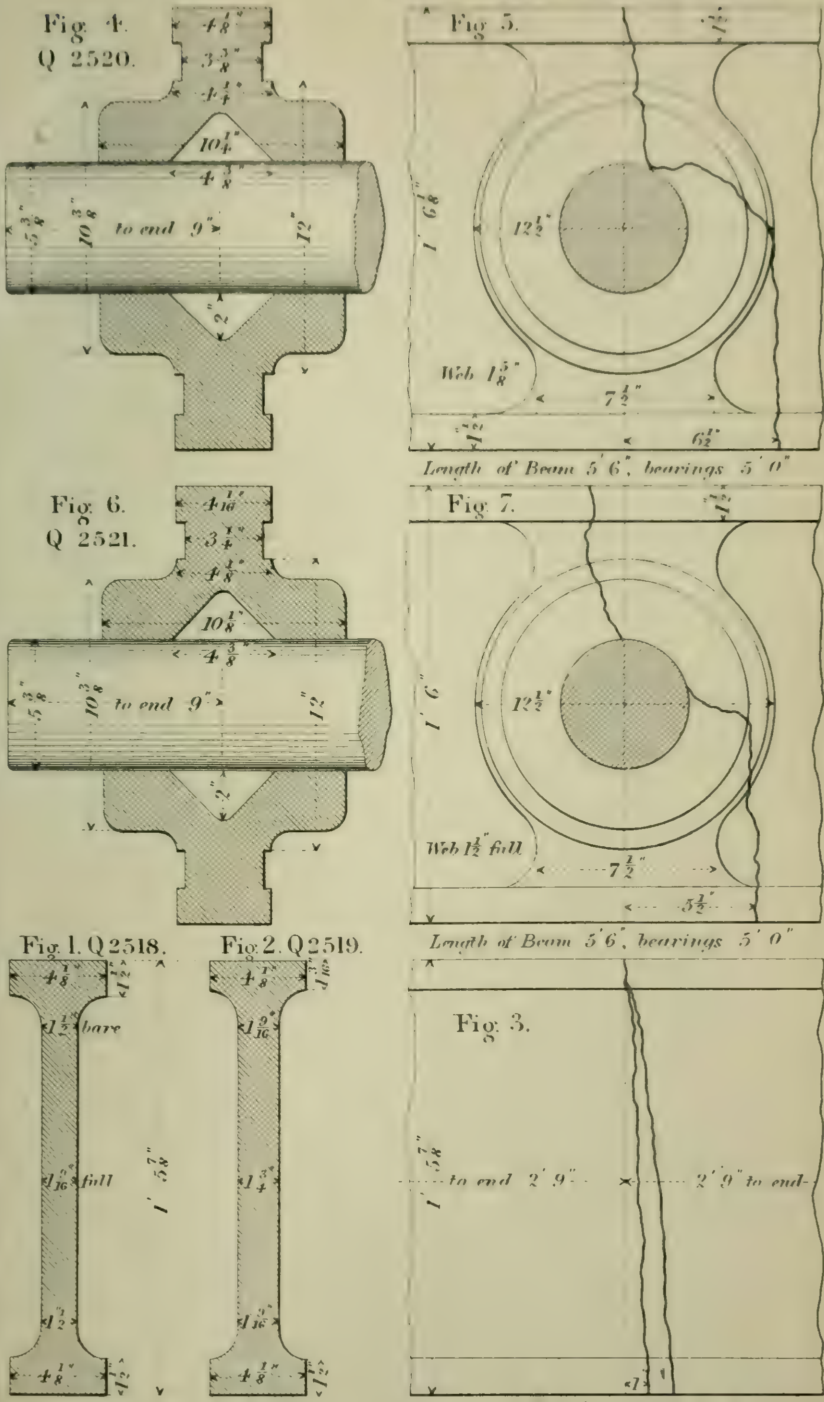


Fig. 3. *Section of Plate before Flanging.*



(Proceedings Inst. M. E. 1882.) *Scale 1 to 8.*



(Proceedings Inst. M.E. 1882.)